Exhaust gases and particles emissions from international shipping. Regulations, monitoring and implementing measures

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***Abstract*—This paper presents the Environmental impacts of international shipping according to preexisting studies and the measures taken by the IMO and the EU to reduce those emissions, emphasizing on EU MRV Regulation.**

***Keywords*—exhaust gas emissions from ships; IMO; EU MRV Regulation**

I. Introduction

Environmental impacts of international shipping are high. The principal exhaust gas emissions from ships include CO2, NOx, SOx, CO, hydrocarbons, and particulate matter. Furthermore, during tanker loading, evaporation leads to additional emissions of hydrocarbons. The exhaust gases are emitted into the atmosphere from the ship stacks and diluted with the ambient air.

MARPOL Annex VI, first adopted in 1997, limits the main air pollutants contained in ships exhaust gas, including sulphur oxides (SOx) and nitrous oxides (NOx), and prohibits deliberate emissions of ozone depleting substances (ODS). MARPOL Annex VI also regulates shipboard incineration, and the emissions of volatile organic compounds (VOC) from tankers.

The EU supports ambitious international action to address climate change. In 2013, the Commission set out a strategy for progressively integrating maritime emissions into the EU's policy for reducing its domestic greenhouse gas emissions.The first step was implementing the system for MRV of emissions that will be analysed below.

II. EMISSIONS FROM INTERNATIONAL SHIPPING: THE LAST 50 YEARS [1]

According to a study by V. Eyring, H. W. Kóhler, J. van Aardenne, and A. Lauer, published on 15 September 2005 Seagoing ships emit exhaust gases and particles into the marine boundary layer andsignificantly contribute to the total budget of anthropogenic emissions.

The study presented an emission inventory for international shipping for the past five decades to be used in global modeling studies with detailed tropospheric chemistry. The inventory is a bottom-up analysis using fuel consumption and fleet numbers for the total civilian and military fleet including auxiliary engines at the end of 2001. Trend estimates for fuel mass, CO_2, NOx, and other emissions for the time between 1950 and 2001 have been calculated using ship number statistics and average engine statistics.

Estimation for total fuel consumption and global emissions for the year 2001 is similar to previous activity-based studies. However, compared to earlier studies, a detailed speciation of nonmethanehydrocarbons (NMHCs) and particulate matter is given, and carbon monoxide emissions are calculated explicitly. The results suggest a fuel consumption of approximately280 million metric tons (Mt) for the year 2001 and 64.5 Mt in 1950. This corresponds to187 (5.4) Tg CO_2 (NOx) in 1950, and 813 (21.4) Tg CO_2 (NOx) in 2001. From 1970 to 2001 the world-merchant fleet increased rapidly in terms of ship numbers, with a corresponding increase in total fuel consumption. The fuel consumption estimates are compared against historical marine bunker fuel statistics, and our emission estimates are related to emission budgets of other transport modes. Global ship emissions are distributed geographically according to global vessel traffic densities of the AMVER (Automated Mutual-assistance Vessel Rescue system) data set for the year 2000. This work also sets the basis to develop future emission scenarios based on average-fleet emission indices.

The principal exhaust gas emissions from ships include CO_2, NOx, SOx, CO, hydrocarbons, and particulate matter. Furthermore, during tanker loading, evaporation leads to additional emissions of hydrocarbons. The exhaust gases are emitted into the atmosphere from the ship stacks and diluted with the ambient air. During the dilution process inside the ship plumes they are partly chemically transformed or removed. The emissions can regionally and globally change the composition of the atmosphere, are radiatively active and have a climate impact. An accurate assessment of the impact of the shipping emissions on the atmosphere requires detailed knowledge of the emission patterns and fluxes. Several emission inventories for shipping based on energy statistics have been established in the past [Olivier et al., 1996; Corbett and Fischbeck, 1997; Corbett et al., 1999; Endresen et al., 2003]. Corbett and Ko¨hler [2003] published an updated inventory for global fuel burned by internationally registered ships above 100 gross tons (GT), based on international shipping statistics [Lloyd's Maritime Information System (LMIS), 2002] for September 2001. This represents an activity-based estimate including main propulsion and auxiliary engine equipment onboard both cargo and noncargo ships, and the military fleet. The total worldwide fleet fuel consumption (civilian and all military ships) in 2001 according to this work is 289 million metric tons (Mt). This estimate is higher than all published inventories that are based on energy statistics.

Even though the first model studies on the impact of ship emissions on ozone used the lower total fuel consumption corresponding to lower NOx emissions of 3.08 Tg (N) per year [Corbett et al., 1999], an overestimate of the impact of shipping on the NOx and ozone distribution results [Lawrence and Crutzen, 1999; Kasibhatla et al., 2000; Davis et al., 2001; Endresen et al., 2003]. This discrepancy can partly be attributed to an inadequate or oversimplified parameterization of chemical dilution within ship plumes [Kasibhatla et al., 2000; Davis et al., 2001; Endresen et al., 2003; Song et al., 2003; von Glasow et al., 2003]. Recent satellite measurements of NO2 from the Global Ozone Monitoring Experiment (GOME) [Burrows et al., 1999] over the Indian Ocean [Beirle et al., 2004] and from the SCIAMACHY (SCanning Imaging Absorption spectroMeter for Atmospheric CHartographY) instrument on board the ENVISAT satellite [Bovensmann et al., 1999] over the Red Sea and the Indian Ocean [Richter et al., 2004] clearly show enhanced NO2 occurrence along the major international shipping routes for the regions studied. Within the uncertainties of the methods applied by Richter et al. [2004] and Beirle et al. [2004], it appears that the observed NO2 column amounts are somewhat lower than those implied by inventories. However, to conclude from these measurements that the lower NOx estimates published by Endresen et al. [2003] are more realistic, would be misleading. Further ship plume model studies and measurements are necessary to clarify these discrepancies.

According to basic statistical information of Lloyd's Maritime Information System (LMIS) [2002] the world merchant fleet at the end of the year 2001 consisted of 89,063 ocean-going ships (43,967 cargo ships and 45,096 noncargo ships) of 100 GT and above. The total cargo fleet included 11,156 tanker (8702 tanker without crude oil carriers and gas carriers, 1301 crude oil carriers, 1153 gas carriers), 2759 container ships, 6261 bulk carriers, 196 combined carriers, and 23,595 general cargo vessels (e.g., lolo ships, roro ships, product carriers, etc.). The non cargo fleet included 971 fish factories, 22,141 fishing vessels, 12,209 tugs, and 9775

Table 1. Fleet-Average Summary for the End of 2001 and for Ships of 100 GT and More[a]

		Cargo Vessels					Noncargo Vessels		
	All Vessels	All Cargo Ships	Tanker[c]	Container Ships	Bulk and Combined Carriers	General Cargo Vessels	Passenger and Fishing Ships, Tugboats, Others	Auxiliary Engines (Gensets)	Military Vessels[b]
Number of ships	90,363	43,967	11,156	2759	6457	23,595	45,096	-	1300
P_{MCR}, MW	343,384	218,733	54,514	46,461	46,297	71,461	67,051	40,000	17,600
F_{MCR}, %			75	72	80	70	65–75	60	80
Time τ,[d] hours/yr			6500	6600	5400	6500	4000–5500	3000	2500
SFOC,[e] g/kWh	212	210	191–229	194–222	192–202	200–230	207–240	230–240	250–280
FC,[f] Mt	279.7	207.8	56.8	42.7	39.4	68.9	46.2	16.3	9.4
EI_{NOx}, g/kWh	16.2	-	9.3–16.8	11.9–18.8	10.9–16.8	10.9–15.8	7.9–10.9	8.9	8–15
kg/t fuel	76.4	85.9	50–90	64–101	58–90	58–85	42–58	48	42–80
TE_{NOx}, Tg NO_2	21.38	17.85	4.44	4.67	3.78	4.96	2.39	0.8	0.34
EI_{CO2}, g/kWh	616	605	600	600	610	610	620	625	800
Kg/t fuel	2905	2860	2830	2830	2880	2880	2930	2950	3776
TE_{CO2}, Tg CO_2	812.63	593.76	160.89	120.93	113.47	198.47	135.23	48.03	35.61
EI_{SOx}, g/kWh	9.12	9.47[g]	9.47[g]	9.47[g]	9.47[g]	9.47[g]	8.52[h]	8.52[h]	3.80[i]
Kg/t fuel	43.0	44.7[g]	44.7[g]	44.7[g]	44.7[g]	44.7[g]	40.2[h]	40.2[h]	18.0[i]
TE_{SOx}, Tg SO_2	12.03	9.34[g]	2.54[g]	1.91[g]	1.81[g]	3.08[g]	1.86[h]	0.66[h]	0.17[i]
EI_{HC},[j] g/kWh	1.5	1.4	1.4	1.4	1.4	1.4	1.7	1.8	1.6
Kg/t fuel	7.0	6.6	6.6	6.6	6.6	6.6	8.0	8.5	7.6
TE_{HC}, Tg HC	1.96	1.38	0.38	0.28	0.26	0.46	0.37	0.14	0.07
EI_{PM},[j] g/kWh	1.27	1.25	1.25	1.25	1.3	1.3	1.4	1.2	1.0
Kg/t fuel	6.0	5.9	5.9	5.9	6.1	6.1	6.6	5.7	4.72
TE_{PM}, Tg PM	1.67	1.23	0.32	0.25	0.24	0.42	0.31	0.09	0.04
EI_{CO},[j] g/kWh	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.7
Kg/t fuel	4.67	4.72	4.72	4.72	4.72	4.72	4.72	4.72	3.3
TE_{CO}, Tg CO	1.306	0.98	0.268	0.201	0.186	0.325	0.218	0.077	0.031

[a]The table summarizes the installed engine power (P_{MCR}), the engine load cycle based on duty cycle profiles (F_{MCR}), the average annual engine running hours (τ), the specific fuel oil consumption (*SFOC*) and specific emission for each pollutant X (EI_x) for each of the main ship classes. The calculated total fuel consumption *FC* (in Mt/yr) and total emission (TE_X) for each pollutant (in Mt X/yr) are also listed. Average emission factors for all vessels have been calculated from the resulting total emission of each pollutant divided by the total fuel consumption of 280 Mt.

[b]About 300 GT and above (equals approximately 100 t standard displacement and more) including some 520 submarines, 190 of which are nuclear powered. The total navy fleet consists of almost 20,000 military ships (including 750 submarines) with 34,633 main engines and a total installed engine power (MCR) of 172,478 MW.

[c]Including 1301 crude oil carriers and 1153 gas carriers.

[d]From engine start to total engine stop, including port operation.

[e]Minimum/maximum values taking into account engine type (two-stroke, four-stroke, turbines), engine cylinder rating, fuel type, with SFOC tolerance (3 and 5%), engine driven pumps, SFOC increase due to the average ship age of some 20 years.

[f]The 2% reduction of the *Corbett and Köhler* [2003] figures due to the lower installed MCR in mid 2001 compared to the end of 2001.

[g]Average fuel-sulfur content 2.4–2.6%.

[h]Average fuel-sulfur content 2.25%.

[i]Average fuel-sulfur content 1.0%.

[j]Tolerance ±20% for HC, PM, and CO; HC and CO emission measurements according to ISO 8178, PM according to VDI 2066 or U.S. EPA method 17.

other ships (e.g., ferries, passenger ships, cruise ships, research vessels, dredgers, cable layers, etc). Table 1 summarizes the fleet-average values for different ship types and the total fleet which have been used in this study.

The study estimates the world fleet fuel consumption for the year 2001 to be approximately 280 million metric tons. Global annual emission budgets for the year 2001 are estimated to be 21.38Tg (NO2) for NOx, 12.03 Tg (SO2) for SOx, 812.6 Tg (CO_2) for CO_2, 1.31 Tg (CO) for carbon monoxide, 1.67 Tg for particulate matter and 1.96 Tg (HC) for hydrocarbons. In addition, 1.959 Tg (HC) hydrocarbons from crude oil transport evaporate yearly during loading, transport, and unloading [Endresen et al., 2003].

The total estimate of CO and HC emissions is based on an average emission index of 4.67 and 7.0 kg/t fuel, respectively. The measurements at the manufacturers' engine test beds are according to ISO 8178 with a tolerance of ±20%. Limited field observations of ship plumes have shown first indications that CO emissions vary significantly between different ship types and that large marine vessels emit very little to no CO (T. B. Ryerson and E. J. Williams, NOAA, personal communication). Also the maintenance of the engine might play an important role. In general, CO emission is the result of incomplete combustion. Since large-bore diesel engines operate at high air excess ratios and high combustion temperatures, carbon monoxide emissions from diesel engines are much lower than from other internal combustion engines. In our study this is reflected by the fact that the average emission index of CO is low compared to all other emissions (see Table 1). To includeemissions from BC, OC, CH_4 and speciated NMHC the data from this study was modified as follows: The emissions of PM10 are 1.67 Tg in total. Using the emission factor for black carbon (BC) measured by Sinha et al. [2003] (0.18 g per kg fuel), the BC fraction estimated from the total fuel consumption of 280 Tg is 0.05 Tg. This result is consistent with the work of Petzold et al. [2004], who measured the exhaust gas of a single-cylinder test bed diesel engine. The engine was operated at various load conditions, running on fuel with a sulfur content of 3.45 wt.–%. For anengine load of 100%, Petzold et al. [2004] measured a BC fraction of 2% of the total particle mass. The BC fraction increases with decreasing engine load. Thus, the resulting total BC emissions of 0.033 Tg estimated from this measurement have to be regarded as a lower boundary. In an analogous manner, the amounts of organic carbon (OC), sulfate (SO_4) and fly ash can be estimated. Petzold et al. [2004] found a mass fraction of 8% (OC), 47% (SO_4) and 6% (ash) of total particle mass at 100% load. This results in global annual emissions of 0.134 Tg (OC), 0.785 Tg (SO4) and 0.100 Tg (ash).

Hydrocarbon emissions have been compiled into a format suitable for atmospheric modeling using the speciation into 25

Table 2. NMHC Speciation of Ship Emissions[a]

	Fuel Combustion				*Tanker Loading*	
	Gas Oil, Mg	Fuel Oil, Mg	Fraction	Tg NMHC	Fraction	Tg NMHC
v01: Alkanols	-	-	-	-	-	-
v02: Ethane	-	-	-	-	0.093	0.155
v03: Propane	-	-	-	-	0.258	0.429
v04: Butanes	-	-	-	-	0.272	0.453
v05: Pentanes	-	-	-	-	0.146	0.243
v06: Hexanes and higher alkanes	159	3	0.302	0.525	0.056	0.093
v07: Ethene	22	90	0.209	0.364	-	-
v08: Propene	11	112	0.229	0.398	-	-
v09: Ethyne	0	3	0.006	0.010	-	-
v10: Isoprenes	-	-	-	-	-	-
v11: Monoterpenes	-	-	-	-	-	-
v12: Other alkenes	0	12	0.022	0.038	-	-
v13: Benzene	11	39	0.093	0.163	0.001	0.002
v14: Toluene	11	17	0.052	0.090	0.002	0.003
v15: Xylenes	17	6	0.043	0.075	0.006	0.010
v16: Trimethylbenzenes	20	0	0.037	0.064	-	-
v17: Other aromatics	-	-	-	-	0.076	0.126
v18: Esters	-	-	-	-	-	-
v19: Ethers	-	-	-	-	-	-
v20: Chlorinated hydrocarbons	-	-	-	-	-	-
v21: Methanal	-	-	-	-	-	-
v22: Other alkanals	-	-	-	-	-	-
v23: Alkanones	-	-	-	-	-	-
v24: Acids	-	-	-	-	-	-
v25: Other NMHC	3	0	0.006	0.010	0.091	0.151
Total NMHC	254	282	1.000	1.737	1.000	1.665

[a]Total emissions of 1.737 Tg NMHC as calculated in this work have been assigned to each of the 25 NMHC categories as identified in EDGAR [*Olivier et al.*, 1996] using the measurement data from *Cooper et al.* [1996]. *Cooper et al.* [1996] distinguish gas oil and fuel oil emissions, of which the average has been used to assign the NMHC emissions. NMHC emissions from tanker loading (1.665 Tg) have been taken from *Endresen et al.* [2003] and are assigned to the 25 NMHC categories using data on evaporation from oil tanks [*EPA*, 2004].

categories of nonmethane volatile organic compounds from the Emission Database for Global Atmospheric Modeling v2 (EDGAR [Olivier et al., 1996]).(Table 2).

Table 3 summarizes global emissions from international shipping presented in this study and compares the results to estimates of the work by Corbett and Ko¨hler [2003] likewise for 2001 and by Endresen et al. [2003] for 2000.

Table 3. Annual Emissions From International Shipping Estimated by E2003 [*Endresen et al.*, 2003] for the Year 2000, by CK2003 [*Corbett and Köhler*, 2003] for September 2001, and in This Study for End of 2001[a]

		E2003	CK2003	This Study	
Total fuel consumption	**Mt**	**166**	**289**	**280**	
NO_x	Tg NO_2	11.92	22.57	**21.38**	
CO_2	Tg CO_2	557.32	912.37	**812.63**	
CO	Tg CO	1.12	-	**1.31**	
SO_x	Tg SO_2	6.82	12.98	**12.03**	
Particulate matter			-		
BC	Tg BC	-	-	0.05	
OC	Tg OC	-	-	0.134	
SO_4	Tg SO_4	-	-	0.785	
Ash	Tg ash	-	-	0.100	
Other particulate matter	Tg	-	-	0.601	
Total particulate matter	Tg PM_{10}	**0.912**	**1.64**	**1.67**	
Hydrocarbons				**fuel**	**loading**
CH_4	Tg	**0.046**	-	**0.223**	**0.294**
v02: Ethane	Tg	b	-	-	0.155
v03: Propane	Tg	b	-	-	0.429
v04: Butanes	Tg	b	-	-	0.453
v05: Pentanes	Tg	b	-	-	0.243
v06: Hexanes higher alkanes	Tg	b	-	0.525	0.093
v07: Ethene	Tg	b	-	0.364	-
v08: Propene	Tg	b	-	0.398	-
v09: Ethyne	Tg	b	-	0.010	-
v12: Other alkenes	Tg	b	-	0.038	-
v13: Benzene	Tg	b	-	0.163	0.002
v14: Toluene	Tg	b	-	0.090	0.003
v15: Xylenes	Tg	b	-	0.075	0.010
v16: Trimethylbenzenes	Tg	b	-	0.064	-
v17: Other aromatics	Tg	b	-	-	0.126
v25: Other NMHC	Tg	b	-	0.010	0.151
Total NMHC	Tg	**0.359**	-	**1.737**	**1.665**
Total hydrocarbons	Tg	**0.405**	**0.769**	**1.96**	**1.96**

[a]The split of particulate matter into BC, OC, SO_4 and ash is taken from *Sinha et al.* [2003] and *Petzold et al.* [2004]. The HC estimates have been split into NMHC and CH_4 using the ratios from E2003. For HC evaporation from tanker loading, transport and uploading the values from E2003 have been used. NMHC emissions have been fitted to the EDGAR NMHC classification [*Olivier et al.*, 1996]. For fuel combustion the fit is based on measurements by *Cooper et al.* [1996] and for tanker loading on *EPA* [2004].
[b]Since the NMHC speciation by *Endresen et al.* [2003] does not match with the 25 categories of EDGAR, this speciation has been excluded here.

Total emissions calculated in this study have been gridded using the global distribution of vessel traffic densities for the year 2000 based on the reported distributions from AMVER data with a 1ox1o spatial resolution [Endresen et al., 2003] for different ship types (tanker, container ships, bulk carriers, and rest). Endresen et al. [2003] used the same global distribution from AMVER, but a sum of 3.63 Tg (N) for the annual total NOx emissions from ship engines instead of 6.51 Tg (N) for the year 2001 as used in this work. As an example the resulting global NOx emission inventory for oil tanker, container vessels, bulk carriers and the total fleet for the year 2001 is shown in Figure 1.

It seems marine fuel consumption and ship emissions have been systematically underestimated in the past. Figure 2 shows the change in international marine bunker fuel statistics in Mt of oil equivalents (source: energy statistics [IEA, 2003]) for the time period 1971 to 2001 compared to the change in the total number of ships (>100 GT) [LMIS, 2002] as well as the estimated total fleet fuel consumption of this work over the same time period. From 1970 to 2001 the world-merchant fleet increased rapidly in terms of ship numbers (by 70%), with a corresponding increase in total fuel consumption. During the time period of rapid increase of the fleet, with the most significant increase in the eighties, marine bunker statistics surprisingly give approximately constant and even lower figures. World seaborne trade since 1985 as on average gained 3.3% in terms of volumes and 3.6% p.a. in terms of ton-miles [Fearnresearch, 2004].

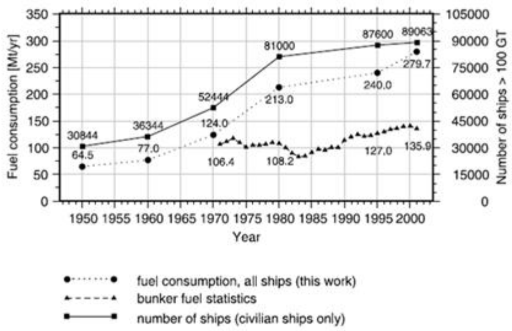


Figure 2. Number of civilian ships (>100 GT) for the time period 1950 to 2001 [*ISL*, 1994; *LMIS*, 2002] as well as the estimated total fleet fuel consumption (civilian, military, and auxiliary) from this work and international marine bunker fuel statistics in million ton of oil equivalents (Mt) (source: *IEA* [2003]).

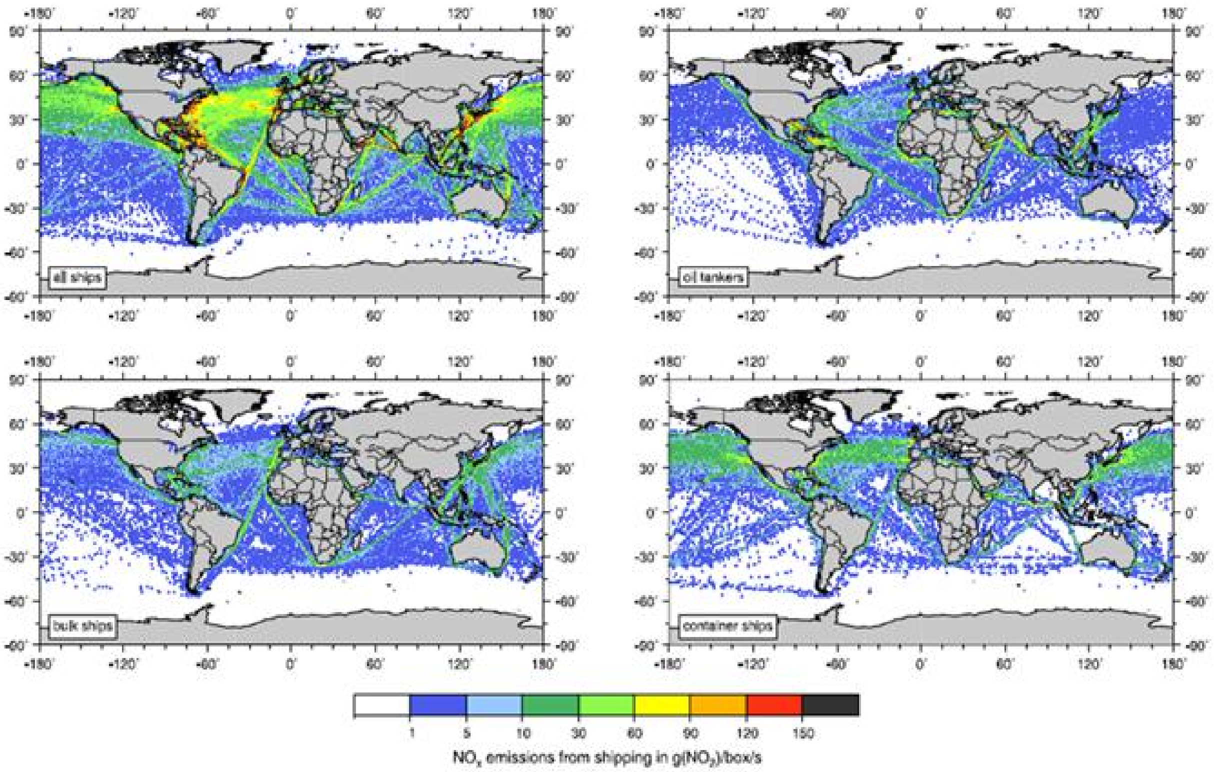


Figure 1. Global distribution of NO_x emissions for different ship types. Global NO_x emissions of the world fleet have been estimated to be 21.38 Tg (NO_x), whereof tankers contribute with 4.44 Tg (NO_x), container ships with 4.67 Tg (NO_x), and bulk carriers with 3.78 Tg (NO_x) (see Table 1). Global distribution of vessel traffic densities for the different ship types and the year 2000 are based on the reported distributions from AMVER data [*Endresen et al.*, 2003].

II.I. Emissions From International Shipping Over the Past Decades

To estimate past fuel consumption rates of the fleet and, from that, exhaust gas emissions, the method as described above could be used. However, this would require reliable input data such as detailed ship and engine as well as engine performance statistics, none of which are available for earlier decades. The detailed fleet structure before 1970 is not known either, and some of the modern ship types did not even exist in the early 1950s or 1960s. The ship fleet at this time consisted of vessels commissioned in 1940 or even in 1930, equipped with lowefficiency power plants without any existing technical documentation (duty profiles, fuel consumption rates,exhaust gas emissions) which could have been helpful for this study. Needless to say, 40 or 50 years ago, emissions and pollutants from ships were not a topic at all, not even mentioning that the measurement equipments for gaseous or solid trace substances like CO, HC, PM with the necessary accuracy were not available.

What is reliably known as the basis for emission estimates for the past decades is the development of the world civilian shipping in terms of ship numbers and the accumulated associated gross tonnage. In 1950 the civilian fleet consisted of 30,844 vessels of 100 GT and above with a total of 84.6 million GT [ISL, 1994]. An indication of the installed engine power onboard early engine-driven ships can be taken from statistics released by UK's trade magazine''The Motor Ship'' since 1953. Unfortunately this table lists only the larger vessels above a deadweight tonnage (Dwt) of 2000. Deadweight tonnage is a unit of measurement expressed in tons of the maximum permitted load of a ship, i.e. the weight of cargo, passengers, fuel, stores and crew when loaded down to its maximum summer load line [ISL, 1994]. 2000 Dwt roughly equals 1300 GT, whereas this work considers all ships of 100 GT and above. But the mean ship engine output for these larger ships is clearly increasing with time on a long-term basis, even though not with the same percentage on a year-to-year basis. Whereas in 1953 the average ship engine output for a ship of 2000 Dwt and above was 4725 kW, it was 4820 kW in 1960, 6545 kW in 1965, 5900 kW in 1970, 8290 kW in 1975, and 8704 kW in 1978.

For the present work we have estimated historical emissions back to 1950. The results can be seen in Figures 2 and 4. The upper line shows the ship number for all civilian vessels with 100 GT and above. Starting around 1960, the world merchant fleet increased rapidly: the ship number more than doubled in the period between 1960 and 1980. Part of this ship boom was the tanker business, which reached its peak around 1973 – 1975, and the introduction of a new type of cargo ship, the container vessel.

For the estimation of fuel consumption, CO_2 and NOx emissions the following assumptions were made:

1. The structure of the ocean-going fleet of the earlier decades, i.e. the classification according to main types of ships, is similar to that of 2001.

2. Merchant and military fleet show similar developments between 1950 and 2001.

3. The average ship-based engine output for the fleet with ships greater than 100 GT could be exactly calculated for the years 2001 (3.2 MW/ship), 1995 (2.81 MW/ship) and 1980 (2.72 MW/ship) and was extrapolated back to 1950 by taking into account the average propulsive power per vessel for the ships of 2000 Dwt and more as mentioned above.

4. Slightly lower annual engine running hours as those used for the 2001 calculation (reducing the fleets' total fuel consumption) and lower engine efficiencies of the earlier engine generations (leading to somewhat higher specific fuel-oil consumption rates (SFOC)) are considered. The effects of these two factors nearly compensate each other.

5. All propulsion engines started-up in 1995 and earlier were strictly fuel-optimized and not NOx-optimized, resulting in a correspondingly higher NOx emission factor than for the state-of-the-art emission-regulated ship engines which are part of the fleet in 2001.

6. For the fleet in 1970 and earlier, the share of steamships was much higher, leading to lower NOx emissions.

7. The writers estimate started from the exact values for 2001 summarized in Table 1. For earlier years, first the total fleet's accumulated installed engine output (in MW) was calculated by multiplying the corresponding ship numbers with the average engine output per ship (MW/ship). To achieve the engines' fuel amount, the resulting total fleet's accumulated installed engine output was multiplied with the fuel amount (in tons per MW output), burned by the fleet in the preceding year. This fuel amount was corrected by the assumed change in annual running hours and SFOC. Finally, the trend estimates CO_2 and NOx emissions were determined.

All other emissions (CO, SO_2, particulate matter, methane, and NMHCs) have been scaled with the historical fuel consumption, starting with the 2001 value as calculated in this study. Historical emissions from tanker loading have been determined by applying the ratio between total CH_4 and NMHC from tanker loading as calculated by Endresen et al. [2003] to the emissions from fuel combustion as calculated in this work. All results for the years 1950, 1960,1970, 1980, 1995 and 2001 are summarized in Table 4.

Table 4. Changes of the World Fleet Over the Past Decades[a]

		1950	1960	1970	1980	1995	**2001**
Number of ships (>100 GT)		30,844	36,344	52,444	81,000	87,600	**89,063**
Total fuel consumption	Mt	64.5	77	124	213	240	**280**
NO_x	Tg NO_2	5.4	6.6	10.7	18.5	20.8	**21.4**
CO_2	Tg CO_2	187	224	360	619	697	**813**
CO	Tg CO	0.30	0.36	0.58	0.99	1.12	**1.31**
SO_2	Tg SO_2	2.77	3.31	5.33	9.16	10.32	**12.03**
Particulate matter	Tg PM_{10}	0.39	0.46	0.74	1.27	1.43	**1.67**
CH_4	Tg	0.12	0.14	0.23	0.40	0.45	**0.52**
NMHC	Tg	0.78	0.84	1.51	2.58	2.91	**3.40**
Total hydrocarbons	Tg	0.90	1.08	1.74	2.98	3.36	**3.92**

[a]The table summarizes the number of civilian ships (>100 GT), annual fuel consumption of the total fleet (including all civilan and military ships and auxiliary engines), and total emission estimates as calculated in this study.

II.II. Comparison to Emissions From Other Transport Modes

The exhaust composition of different transport modes strongly depends on the fuel burned, the size of the engine and additional technological optimizations, e.g., with respect to NOx emissions. Although shipping contributes only about 16% to the total fuel consumption of all traffic related sources (aviation: 207 Mt, international shipping: 280 Mt, road traffic: 1320 Mt), ship emissions significantly contribute to emissions of pollutants from all transport modes, particularly because there have been no strict international emission regulations in the past as for road traffic and aviation.

A summary of the total fuel consumption, CO_2, NOx, SOx and PM10 emissions for the year 2000 and a comparison of the three transport modes shipping, aviation and road traffic is given in Figure 3.

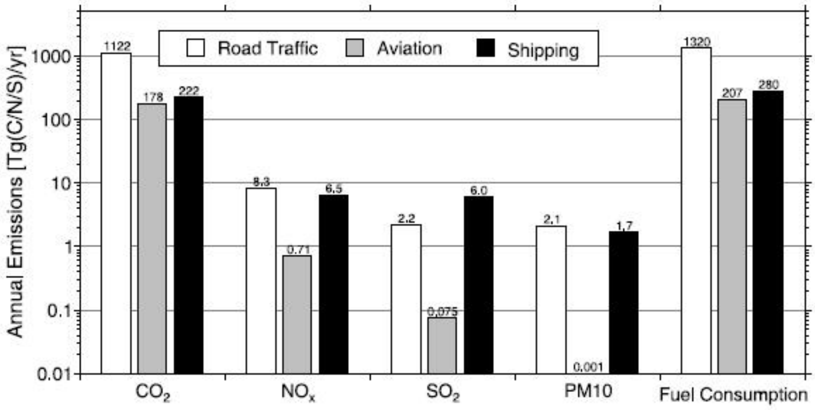


Figure 3. Transport-related annual emissions of CO_2 in Tg (C), NO_x in Tg (N), SO_2 in Tg (S), and PM_{10} in Tg (PM) and the fuel consumption in Mt estimated for the year 2000. PM_{10} from road traffic includes black (BC) and organic carbon (OC) only. For details and references, see text.

Although shipping contributes only about 16% to the total fuel consumption of all traffic related sources, ship emissions significantly contribute to emissions of pollutants from all transport modes. The ocean-going fleet produces about 9.2 (0.8) times more NOx emissions than aviation (road traffic), but due to a high sulfur content in the fuel about 80 (2.7) times more SOx emissions. Shipping emits approximately 1200 times more particulate matter than aviation. The comparison of total emission from different transport modes demonstrates that clear information is needed on the climate impact of ship emissions, to allow the industry to incorporate, with greater confidence, environmental considerations into their design and development work.

II.III. Specific evaluation of emissions from shipping including assessment for the establishment of possible new emission control areas in European Seas [2]

On March 2013 a report by Paul Campling and Liliane Janssen (VITO), Kris Vanherle (TML) , Janusz Cofala, Chris Heyes, and Robert Sander (IIASA) was published describing the results of one of the sectoral studies undertaken in connection with the Service Contract on Monitoring and Assessment of Sectorial Implementation Actions (ENV.C3/SER/2011/0009) of DG Environment of the European Commission. The study presents scenarios of air emissions from international shipping on the seas surrounding Europe. The approach adopted was to develop further the EX-TREMIS/ EUROSTAT/ EUROMOSS (EEE) database and integrate this information with a digital European shipping routes map. Emissions have been estimated for the medium-term (up 2030) and for the long-term (2050). Results of this study will be used within the work on the revision of the EU Thematic Strategy on Air Pollution (TSAP).

Analysis starts with the Baseline projection, which combines current expectations regarding development of maritime transport with the effects of existing legislation on ship emissions. Scenarios explore effects of measures that go beyond the current legislation. These include establishing additional emission control areas (ECAs) on sea regions and zones with particularly high impact on land-based receptors, reducing cruising speed of vessels (slow steaming) as well as switching to cleaner fuels (LNG).

Available options have been combined into nine scenarios. Scenario 1 explores effects of implementing the NECA standards (on top of the existing SECA legislation) in the Baltic and North Seas (with English Chanel), together with SECA and NECA within the territorial waters of the EU Member states. Scenario 2 assumes the extension of ECA legislation to Exclusive Economic Zones (EEZ). Scenarios 3 to 5 consider various ways to reduce emissions from the Mediterranean and Black Seas. Scenario 6 and its variants explore the effects of slow steaming. Scenario 7 demonstrates the possible reduction of fine particles emissions through fitting vessels with particle filters. Finally, the Maximum Technically Feasible Reduction (MTFR) case (Scenario 8) demonstrates the potential to reduce emissions through implementation of all technical measures on new and existing vessels in all European seas. Scenario 9 (Maximum Control Efforts - MCE) combines the MTFR assumptions with slow steaming. In a separate sensitivity, the effects of using LNG for short sea shipping are demonstrated.

In 2005, ships emitted about 1.7 million tons of SO2, which was about 20 % of the emissions from land-based sources in the EU-27. Emissions of NOx (2.8 million tons) were equivalent to 25% land-based emissions. About 30 % of these emissions occurred on the Territorial Seas of the EU Member States, i.e., within 12 nm from the coast. Emissions from the Exclusive Economic Zones (200 nm) were approximately 75% of the total.

Contribution of shipping to air pollution in coastal zones is high. In 2005, 35% of sulfur deposition in coastal areas originated from international shipping and exceeded 0.2 g/m2/year, with maximum values up to 0.5 to 1.0 g/m2.

Recent changes in legislation on emissions from shipping (IMO MARPOL Annex VI) will importantly reduce air pollution from ships. Under the Baseline assumptions, the emissions of SO2 from the European seas will decrease by 82% in 2020 compared to 2005. Emissions of NOx will drop by 13%. After 2020 the Baseline emissions increase due to the increase in transport volume and are in 2030 12 to 13% higher than in 2020.

Implementation of NECA legislation in the Baltic Sea and the North Sea (with English Channel) and ECA for sulfur and nitrogen oxides in the territorial waters of the EU-27 would reduce the emissions in 2030 by 23 kt of SO_2 and 460 kt of NOx. Extension of NECA and SECA to Exclusive Economic Zones (200nm) would cause a drop in emissions by 160 kt of SO2 and 970 kt of NOx compared with the Baseline.

Implementation of slow steaming (speed restrictions) within the Exclusive Economic Zones (200 nm) of the EU Member States has a potential to reduce fuel consumption and emissions in 2030 by approximately 20%.

Implementation of MTFR scenario, in which SECA and NECA standards are implemented in all seas surrounding Europe, would reduce the emissions of sulfur in 2030 by about 73% and nitrogen oxides by 69% compared with the Baseline. PM emissions would drop by 66%. If combined with slow steaming (as in the MCE case), these reductions would be about one quarter higher.

Replacement of oil with LNG as a fuel for shipping reduces air pollution. If 50% of vessels involved in international short sea shipping1 in the Baltic Sea and the North Sea would use LNG in 2030, the emissions from these two sea regions would decrease by about 25%.

Environmental impacts of international shipping are high. In 2005, air pollution from shipping was responsible for about 14 million life years lost (YOLL), 700 cases of premature deaths due to ozone, and 17 thousand km2 of ecosystems with acid deposition above critical loads. Area of ecosystems endangered by eutrophication, which can be attributed to the emissions from shipping, was 30 thousand km2. For the Baseline situation, negative impacts will persist also in the future and – without further strengthening of legislation - will even increase after 2020.

Described in this report scenarios importantly contribute to mitigating these impacts. Implementation of ECA for sulfur and nitrogen in Territorial Seas and the Exclusive Economic Zones of the EU Member States reduces the health effects caused by shipping emissions in 2030 by one third. Area of ecosystems affected by acidification and eutrophication due to shipping activities decreases by about 45%. The MTFR scenario reduces shipping contribution to air pollution by about two thirds.

Costs of scenarios depend on the spatial coverage and the type of measures applied. Establishing NECA in the Baltic and the North Sea (with English Channel) costs in 2030 about 270 million €. Extension of SECA and NECA to all EU territorial waters increases these costs to about 740 M€. Costs are about 270 M€ lower in case scrubbers were used instead of low sulfur fuel. Establishing NECA and SECA in the EU territorial and EEZ waters would cost 3.2 bln € (for low S fuels option) or 1.3 bln € (for the case of application of scrubbers). Using PM filters on top of SECA and NECA legislation in in the Baltic, Black, Mediterranean and the North Sea (with English Channel) would be relatively inexpensive – about 66 million €. Finally, MTFR over the whole area of European seas costs 5.4 billion € (low S fuels case) or 2.4 billion € (with scrubbers).

III. INTERNATIONAL CONVENTION FOR THE PREVENTION OF POLLUTION FROM SHIPS (MARPOL) / ANNEX VI PREVENTION OF AIR POLLUTION FROM SHIPS. [3]

The International Convention for the Prevention of Pollution from Ships (MARPOL) is the main international convention covering prevention of pollution of the marine environment by ships from operational or accidental causes.

The MARPOL Convention was adopted on 2 November 1973 at IMO. The Protocol of 1978 was adopted in response to a spate of tanker accidents in 1976-1977. As the 1973 MARPOL Convention had not yet entered into force, the 1978 MARPOL Protocol absorbed the parent Convention. The combined instrument entered into force on 2 October 1983. In 1997, a Protocol was adopted to amend the Convention and a new Annex VI was added which entered into force on 19 May 2005. MARPOL has been updated by amendments through the years.

The Convention includes regulations aimed at preventing and minimizing pollution from ships - both accidental pollution and that from routine operations - and currently includes six technical Annexes. Special Areas with strict controls on operational discharges are included in most Annexes.

i. Annex I Regulations for the Prevention of Pollution by Oil (entered into force 2 October 1983)
Covers prevention of pollution by oil from operational measures as well as from accidental discharges; the 1992 amendments to Annex I made it mandatory for new oil tankers to have double hulls and brought in a phase-in schedule for existing tankers to fit double hulls, which was subsequently revised in 2001 and 2003.

ii. Annex II Regulations for the Control of Pollution by Noxious Liquid Substances in Bulk (entered into force 2 October 1983)
Details the discharge criteria and measures for the control of pollution by noxious liquid substances carried in bulk; some 250 substances were evaluated and included in the list appended to the Convention; the discharge of their residues is allowed only to reception facilities until certain concentrations and conditions (which vary with the category of substances) are complied with.
In any case, no discharge of residues containing noxious substances is permitted within 12 miles of the nearest land.

iii. Annex III Prevention of Pollution by Harmful Substances Carried by Sea in Packaged Form (entered into force 1 July 1992)
Contains general requirements for the issuing of detailed standards on packing, marking, labelling, documentation, stowage, quantity limitations, exceptions and notifications.
For the purpose of this Annex, "harmful substances" are those substances which are identified as marine pollutants in the International Maritime Dangerous Goods Code (IMDG Code) or which meet the criteria in the Appendix of Annex III.

iv. Annex IV Prevention of Pollution by Sewage from Ships (entered into force 27 September 2003)
Contains requirements to control pollution of the sea by sewage; the discharge of sewage into the sea is prohibited, except when the ship has in operation an approved sewage treatment plant or when the ship is discharging comminuted and disinfected sewage using an approved system at a distance of more than three nautical miles from the nearest land; sewage which is not comminuted or disinfected has to be discharged at a distance of more than 12 nautical miles from the nearest land.

v. Annex V Prevention of Pollution by Garbage from Ships (entered into force 31 December 1988)
Deals with different types of garbage and specifies the distances from land and the manner in which they may be disposed of; the most important feature of the Annex is the complete ban imposed on the disposal into the sea of all forms of plastics.

vi. Annex VI Prevention of Air Pollution from Ships (entered into force 19 May 2005)
Sets limits on sulphur oxide and nitrogen oxide emissions from ship exhausts and prohibits deliberate emissions of ozone depleting substances; designated emission control areas set more stringent standards for SOx, NOx and particulate matter. A chapter adopted in 2011 covers mandatory technical and operational energy efficiency measures aimed at reducing greenhouse gas emissions from ships.

III.I. Annex VI Prevention of Air Pollution from Ships

MARPOL Annex VI, first adopted in 1997, limits the main air pollutants contained in ships exhaust gas, including sulphur oxides (SOx) and nitrous oxides (NOx), and prohibits deliberate emissions of ozone depleting substances (ODS). MARPOL Annex VI also regulates shipboard incineration, and the emissions of volatile organic compounds (VOC) from tankers.

Following entry into force of MARPOL Annex VI on 19 May 2005, the Marine Environment Protection Committee (MEPC), at its 53rd session (July 2005), agreed to revise MARPOL Annex VI with the aim of significantly strengthening the emission limits in light of technological improvements and implementation experience. As a result of three years examination, MEPC 58 (October 2008) adopted the revised MARPOL Annex VI and the associated NOx Technical Code 2008, which entered into force on 1 July 2010.

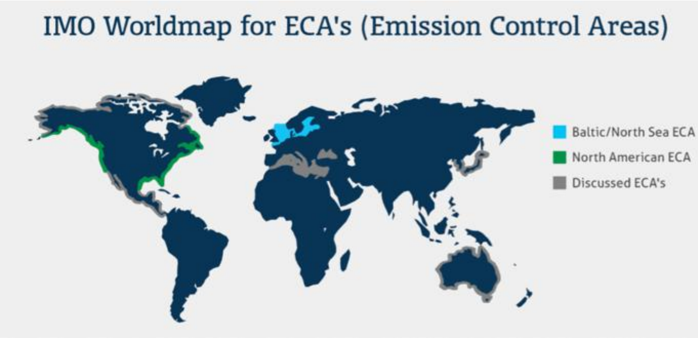
III.II. Revised MARPOL Annex VI

The main changes to MARPOL Annex VI are a progressive reduction globally in emissions of SOx, NOx and particulate matter and the introduction of emission control areas (ECAs) to reduce emissions of those air pollutants further in designated sea areas.

Under the revised MARPOL Annex VI, the global sulphur cap will be reduced from current 3.50% to 0.50%, effective from 1 January 2020, subject to a feasibility review to be completed no later than 2018.

MEPC 70 (October 2016) considered an assessment of fuel oil availability to inform the decision to be taken by the Parties to MARPOL Annex VI, and decided that the fuel oil standard (0.50% sulphur limit) shall become effective on 1 January 2020.

The limits applicable in ECAs for SOx and particulate matter were reduced to 0.10%, from 1 January 2015.



Progressive reductions in NOx emissions from marine diesel engines installed on ships are also included, with a "Tier II" emission limit for engines installed on a ship constructed on or after 1 January 2011; and a more stringent "Tier III" emission limit for engines installed on a ship constructed on or after 1 January 2016 operating in ECAs (North American Emission Control Area and the U.S. Caribbean Sea Emission Control Area). Marine diesel engines installed on a ship constructed on or after 1 January 1990 but prior to 1 January 2000 are required to comply with "Tier I" emission limits, if an approved method for that engine has been certified by an Administration.

The revised NOx Technical Code 2008 includes a new chapter based on the agreed approach for regulation of existing (pre-2000) engines established in MARPOL Annex VI, provisions for a direct measurement and monitoring method, a certification procedure for existing engines and test cycles to be applied to Tier II and Tier III engines.

MEPC 66 (April 2014) adopted amendments to regulation 13 of MARPOL Annex VI regarding the effective date of NOx Tier III standards.

The amendments provide for the Tier III NOx standards to be applied to a marine diesel engine that is installed on a ship constructed on or after 1 January 2016 and which operates in the North American Emission Control Area or the U.S. Caribbean Sea Emission Control Area that are designated for the control of NOx emissions.

In addition, the Tier III requirements would apply to installed marine diesel engines when operated in other emission control areas which might be designated in the future for Tier III NOx control. Tier III would apply to ships constructed on or after the date of adoption by the Marine Environment Protection Committee of such an emission control area, or a later date as may be specified in the amendment designating the NOx Tier III emission control area.

Further, the Tier III requirements do not apply to a marine diesel engine installed on a ship constructed prior to 1 January 2021 of less than 500 gross tonnage, of 24 m or over in length, which has been specifically designed and is used solely, for recreational purposes.

Revisions to the regulations for ozone-depleting substances, volatile organic compounds, shipboard incineration, reception facilities and fuel oil quality were also made with regulations on fuel oil availability added.

The revised measures are expected to have a significant beneficial impact on the atmospheric environment and on human health, particularly for those people living in port cities and coastal communities.

III.III. Energy Efficiency

In 2011, IMO adopted mandatory technical and operational energy efficiency measures which are expected to significantly reduce the amount of CO_2 emissions from international shipping.These mandatory measures (EEDI/SEEMP) entered into force on 1 January 2013.

IMO has adopted important guidelines aimed at supporting implementation of the mandatory measures to increase energy efficiency and reduce GHG emissions from international shipping, paving the way for the regulations on EEDI and SEEMP to be smoothly implemented by Administrations and industry.

The expected growth of world trade represents a challenge to meeting a future target for emissions required to achieve stabilization in global temperatures and so IMO has begun consideration of further technical and operational measures to enhance the energy efficiency of ships.

III.III.I. Energy Efficiency Design Index (EEDI)

The Energy Efficiency Design Index (EEDI) was made mandatory for new ships and the Ship Energy Efficiency Management Plan (SEEMP) for all ships at MEPC 62 (July 2011) with the adoption of amendments to MARPOL Annex VI (resolution MEPC.203(62)), by Parties to MARPOL Annex VI. This was the first legally binding climate change treaty to be adopted since the Kyoto Protocol.

The EEDI for new ships is the most important technical measure and aims at promoting the use of more energy efficient (less polluting) equipment and engines. The EEDI requires a minimum energy efficiency level per capacity mile (e.g. tonne mile) for different ship type and size segments. Since 1 January 2013, following an initial two year phase zero, new ship design needs to meet the reference level for their ship type. The level is to be tightened incrementally every five years, and so the EEDI is expected to stimulate continued innovation and technical development of all the components influencing the fuel efficiency of a ship from its design phase. The EEDI is a non-prescriptive, performance-based mechanism that leaves the choice of technologies to use in a specific ship design to the industry. As long as the required energy efficiency level is attained, ship designers and builders are free to use the most cost-efficient solutions for the ship to comply with the regulations. The EEDI provides a specific figure for an individual ship design, expressed in grams of carbon dioxide (CO_2) per ship's capacity-mile (the smaller the EEDI the more energy efficient ship design) and is calculated by a formula based on the technical design parameters for a given ship.

The CO_2 reduction level (grams of CO_2 per tonne mile) for the first phase is set to 10% and will be tightened every five years to keep pace with technological developments of new efficiency and reduction measures. Reduction rates have been established until the period 2025 and onwards when a 30% reduction is mandated for applicable ship types calculated from a reference line representing the average efficiency for ships built between 2000 and 2010. The EEDI is developed for the largest and most energy intensive segments of the world merchant fleet and embraces emissions from new ships covering the following ship types: tankers, bulk carriers, gas carriers, general cargo ships, container ships, refrigerated cargo carriers and combination carriers. In 2014, MEPC adopted amendments to the EEDI regulations to extend the scope of EEDI to: LNG carriers, ro-ro cargo ships (vehicle carriers), ro-ro cargo ships; ro-ro passenger ships and cruise passenger ships having non-conventional propulsion. These amendments mean that ship types responsible for approximately 85% of the CO_2 emissions from international shipping are incorporated under the international regulatory regime.

Since 2012, Marine Environment Protection Committee (MEPC) adopted/approved or amended following important guidelines aimed at assisting the implementation of the mandatory regulations on Energy Efficiency for Ships in MARPOL Annex VI:

- 2014 Guidelines on survey and certification of the Energy Efficiency Design Index (EEDI), as amended
- 2014 Guidelines on the method of calculation of the attained Energy Efficiency Design Index for new ships, as amended
- 2013 Guidelines for calculation of reference lines for use with the Energy Efficiency Design Index (EEDI)
- 2013 Guidelines for calculation of reference lines for use with the Energy Efficiency Design Index (EEDI) for cruise passenger ships having non-conventional propulsion
- 2013 Interim guidelines for determining minimum propulsion power to maintain the manoeuvrability of ships in adverse conditions, as amended
- 2016 Guidelines for the development of a Ship Energy Efficiency Management Plan (SEEMP)
- 2013 Guidance on treatment of innovative energy efficiency technologies for calculation and verification of the attained EEDI
- Interim Guidelines for the calculation of the coefficient f_w for decrease in ship speed in a representative sea condition for trial use

Finalization and adoption / approval of the supporting guidelines / guidance was a significant achievement which provides sufficient lead time for Administrations and industry to prepare. The guidelines will support Member States in their uniform implementation of the new chapter 4 of MARPOL Annex VI Regulations for the prevention of air pollution from ships

III.IV. Ship Energy Efficiency Management Plan (SEEMP) and Energy Efficiency Operational Indicator (EEOI)

The Ship Energy Efficiency Management Plan (SEEMP) is an operational measure that establishes a mechanism to improve the energy efficiency of a ship in a cost-effective manner. The SEEMP also provides an approach for shipping companies to manage ship and fleet efficiency performance over time using, for example, the Energy Efficiency Operational Indicator (EEOI) as a monitoring tool. The guidance on the development of the SEEMP for new and existing ships incorporates best practices for fuel efficient ship operation, as well as guidelines for voluntary use of the EEOI for new and existing ships (MEPC.1/Circ.684). The EEOI enables operators to measure the fuel efficiency of a ship in operation and to gauge the effect of any changes in operation, e.g. improved voyage planning or more frequent propeller cleaning, or introduction of technical measures such as waste heat recovery systems or a new propeller. The SEEMP urges the ship owner and operator at each stage of the plan to consider new technologies and practices when seeking to optimise the performance of a ship.

III.IV.I. Data collection system for fuel oil consumption of ships

MEPC 70 (October 2016) adopted mandatory MARPOL Annex VI requirements for ships to record and report their fuel oil consumption, by resolution MEPC.278(70).

Under the amendments, ships of 5.000 gross tonnage and above will be required to collect consumption data for each type of fuel oil they use, as well as other, additional, specified data including proxies for transport work. The aggregated data will be reported to the flag State after the end of each calendar year and the flag State, having determined that the data has been reported in accordance with the requirements, will issue a Statement of Compliance to the ship. Flag States will be required to subsequently transfer this data to an IMO Ship Fuel

Oil Consumption Database. IMO will be required to produce an annual report to MEPC, summarizing the data collected.

In addition, on or before 31 December 2018, in the case of a ship of 5,000 gross tonnage and above, the Ship Energy Efficiency Management Plan (SEEMP) shall include a description of the methodology that will be used to collect the data and the processes that will be used to report the data to the ship's flag State.

In this regard, the following guidelines/circular were developed by MEPC:

- 2016 Guidelines for the development of a Ship Energy Efficiency Management Plan (SEEMP) (resolution MEPC.282(70))
- 2017 Guidelines for Administration verification of ship fuel oil consumption data (resolution MEPC.292(71))
- 2017 Guidelines for the development and management of the IMO Ship Fuel Oil Consumption Database (resolution MEPC.293(71)) and
- MEPC circular on Submission of data to the IMO data collection system of fuel oil consumption of ships from a State not party to MARPOL Annex VI (MEPC.1/Circ.871).

According to Resolution MEPC.278(70):

- From calendar year 2019 (i.e. 01/01/2019 to 31/12/2019), each ship of 5,000 gross tonnage and above shall collect the data in a predefined form, for that and each subsequent calendar year or portion thereof, as appropriate, according to the methodology included in the SEEMP.
- At the end of each calendar year, the ship shall aggregate the data collected in that calendar year or portion thereof, as appropriate.
- Within three months after the end of each calendar year, the ship shall report to its Administration or any organization duly authorized by it, the aggregated value for each datum, via electronic communication and using a standardized format.
- Upon verification of the submitted data, the Administration or any organization duly authorized by it will issue to the ship by 31st of May a Statement of Compliance related to fuel oil consumption.
- Finally, the Administration will submit aggregated data to the IMO, which will maintain an anonymized IMO Ship Fuel Oil Consumption Database.

The following information should be submitted to the IMO Ship Fuel Oil Consumption Database: Identity of the ship:

a) IMO number;

Period of calendar year for which the data is submitted:

a) Start date (dd/mm/yyyy)
b) End date (dd/mm/yyyy)

Technical characteristics of the ship:

a) Ship type, as defined in regulation 2 of this Annex or other (to be stated)
b) Gross tonnage (GT)
c) Net tonnage (NT)
d) Deadweight tonnage (DWT)
e) Power output (rated power) of main and auxiliary reciprocating internal combustion engines over 130 kW (to be stated in kW)
f) EEDI (if applicable)
g) Ice class

Fuel oil consumption, by fuel oil type in metric tonnes and methods used for collecting fuel oil consumption data

Distance travelled:

a) Hours underway

In order to collect the required data a new SEEMP Part II has to be developed to outline the methodology used to collect fuel oil consumption data.

The SEEMP Part II shall include information of fuel oil consumption by the main engines, auxiliary engines, gas turbines, boilers and inert gas generator, for each type of fuel oil consumed, regardless of whether a ship is underway or not as well as on the methods to measure distance travelled, hours underway and other information.

SEEMP Part II must be developed following the IMO MEPC.282(70) that includes guidelines for the development of a data collection plan.

Especially SEEMP Part II shall include the following information:

- Ship Particulars (Name of ship; IMO Number, Company; Flag etc.)
- Record of revision
- Ship engines and other fuel oil consumers and fuel oil types used
- Emission factors
- Method to measure fuel oil consumption.
- Methods to measure distance travelled
- Method to measure hours underway
- Process that will be used to report the data to the Administration
- Procedures for data quality

There are three methods for collecting data on annual fuel oil consumption as outlined herewith below:

Method 1: using bunker delivery

Method 2: using flow meters

Method 3: using bunker fuel oil tank monitoring on board

Direct CO_2 emission measurement is not required by regulation 22A of MARPOL Annex VI however, it can be used for collecting data of annual fuel oil consumption. As required by MEPC.282(70) in case of the absence or/and breakdown of direct CO_2 emissions measurement equipment, manual tank readings will be conducted instead. The locations of all equipment applied are described in this monitoring plan. Also, calibration of the CO_2 emissions measurement equipment should be specified. Calibration and maintenance records should be available on board.

Appendix IX of MARPOL Annex VI specifies that distance travelled should be submitted to the Administration and:

- distance travelled over ground in nautical miles should be recorded in the log-book in accordance with SOLAS regulation V/28.13;
- the distance travelled while the ship is underway under its own propulsion should be included into the aggregated data of distance travelled for the calendar year; and
- other methods to measure distance travelled accepted by the Administration may be applied. In any case, the method applied should be described in detail in the Data Collection Plan (i.e. SEEMP Part II).

IV. EU REGULATION 2015/757 ON MONITORING, REPORTING AND VERIFICATION EMISSIONS FROM MARITIME TRANSPORT. [4],[5],[6]

IV.I. EU REGULATION 2015/757

The Commission's 2011 White Paper on transport suggests that the EU's CO_2 emissions from maritime transport should be cut by at least 40% from 2005 levels by 2050, and if feasible by 50%. However, international shipping is not covered by the EU's current emissions reduction targets.

In 2013, the Commission set out a strategy for progressively integrating maritime emissions into the EU's policy for reducing its domestic greenhouse gas emissions.

The gradual approach consists of three subsequent steps:

1. Implementing a system for MRV of emissions
2. Definition of reduction targets for the maritime transport sector
3. Application of a market based measure (MBM).

The Regulation (EU) 2015/757 of the European Parliament and of the Council of 29 April 2015 on the monitoring, reporting and verification of carbon dioxide emissions from maritime transport, and amending Directive 2009/16/EC ("the MRV Shipping Regulation")lays down rules for the accurate monitoring, reporting and verification of carbon dioxide (CO_2) emissions and of other relevant information from ships arriving at, within or departing from ports under the jurisdiction of a Member State, in order to promote the reduction of CO_2 emissions from maritime transport in a cost effective manner.

The Regulation applies to ships above 5 000 gross tonnage in respect of CO_2 emissions released during their voyages from their last port of call to a port of call under the jurisdiction of a Member State and from a port of call under the jurisdiction of a Member State to their next port of call, as well as within ports of call under the jurisdiction of a Member State.

The Regulation does not apply to warships, naval auxiliaries, fish-catching or fish-processing ships, wooden ships of a primitive build, ships not propelled by mechanical means, or government ships used for non-commercial purposes.

Further technical legislation has been adopted by the European Commission to implement the

requirements as regards monitoring and reporting. This includes:

- Commission Delegated Regulation (EU) 2016/2071 of 22 September 2016 on amending Regulation 2015/757 as regards the methods for monitoring CO_2 emissionsand the rules for monitoring other relevant information
- Commission Implementing Regulation (EU) 2016/1928 of 4 November 2016 on determination of cargo carried for categories of ship others than passengers ro-ro and container ships pursuant to Regulation (EU) 2015/7573
- Commission Implementing Regulation (EU) 2016/1927 of 4 November 2016 setting templates for monitoring plans, emissions reports and documents of compliance pursuant to Regulation (EU) 2015/7574

IV.I.I. Common principles for monitoring and reporting

1. In accordance with Articles 8 to 12 of the regulation, companies shall, for each of their ships, monitor and report on the relevant parameters during a reporting period. They shall carry out that monitoring and reporting within all ports under the jurisdiction of a Member State and for any voyages to or from a port under the jurisdiction of a Member State.

2.Monitoring and reporting shall be complete and cover CO2 emissions from the combustion of fuels, while the ships are at sea as well as at berth. Companies shall apply appropriate measures to prevent any data gaps within the reporting period.

3.Monitoring and reporting shall be consistent and comparable over time. To that end, companies shall use the same monitoring methodologies and data sets subject to modifications assessed by the verifier.

4.Companies shall obtain, record, compile, analyse and document monitoring data, including assumptions, references, emission factors and activity data, in a transparent manner that enables the reproduction of the determination of CO_2 emissions by the verifier.

5.Companies shall ensure that the determination of CO_2 emissions is neither systematically nor knowingly inaccurate. They shall identify and reduce any source of inaccuracies.

6.Companies shall enable reasonable assurance of the integrity of the CO_2 emission data to be monitored and reported.

7.Companies shall endeavour to take account of the recommendations included in the verification reports issued pursuant to Article 13(3) or (4) in their subsequent monitoring and reporting.

IV.I.II. Methods for monitoring CO_2 emissions

A. Calculation of CO2 emissions (article 9)

For the purposes of calculating CO2 emissions companies shall apply the following formula:

Fuel consumption × emission factor

Fuel consumption shall include fuel consumed by main engines, auxiliary engines, gas turbines, boilers and inert gas generators. Fuel consumption within ports at berth shall be calculated separately.

In principle, default values for emission factors of fuels shall be used unless the company decides to use data on fuel quality set out in the Bunker Fuel Delivery Notes (BDN) and used for demonstrating compliance with applicable regulations of sulphur emissions.

Appropriate emission factors shall be applied in respect of biofuels and alternative non-fossil fuels.

B.Methods for determining CO2 emissions

The company shall define in the monitoring plan which monitoring method is to be used to calculate fuel consumption for each ship under its responsibility and ensure that once the method has been chosen, it is consistently applied.

Actual fuel consumption for each voyage shall be used and be calculated using one of the following methods:

Bunker Fuel Delivery Note (BDN) and periodic stocktakes of fuel tanks;

Bunker fuel tank monitoring on board;

Flow meters for applicable combustion processes;

Direct CO2 emissions measurements.

Any combination of these methods, once assessed by the verifier, may be used if it enhances the overall accuracy of the measurement.

Method A: BDN and periodic stocktakes of fuel tanks .

This method is based on the quantity and type of fuel as defined on the BDN combined with periodic stocktakes of fuel tanks based on tank readings. The fuel at the beginning of the period, plus deliveries, minus fuel available at the end of the period and de-bunkered fuel between the beginning of the period and the end of the period together constitute the fuel consumed over the period.

The period means the time between two port calls or time within a port. For the fuel used during a period, the fuel type and the sulphur content need to be specified.

This method shall not be used when BDN are not available on board ships, especially when cargo is used as a fuel, for example, liquefied natural gas (LNG) boil-off.

Under existing MARPOL Annex VI regulations, the BDN is mandatory, is to be retained on board for three years after the delivery of the bunker fuel and is to be readily available. The periodic stocktake of fuel tanks on-board is based on fuel tank readings. It uses tank tables relevant to each fuel tank to determine the volume at the time of the fuel tank reading. The uncertainty associated with the BDN shall be specified in the monitoring plan. Fuel tank readings shall be carried out by appropriate methods such as automated systems, soundings and dip tapes. The method for tank sounding and uncertainty associated shall be specified in the monitoring plan.

Where the amount of fuel uplift or the amount of fuel remaining in the tanks is determined in units of volume, expressed in litres, the company shall convert that amount from volume to mass by using actual density values. The company shall determine the actual density by using one of the following:

- on-board measurement systems;
- the density measured by the fuel supplier at fuel uplift and recorded on the fuel invoice or BDN.

The actual density shall be expressed in kg/l and determined for the applicable temperature for a specific measurement. In cases for which actual density values are not available, a standard density factor for the relevant fuel type shall be applied once assessed by the verifier.

Method B: Bunker fuel tank monitoring on-board

This method is based on fuel tank readings for all fuel tanks on-board.

The tank readings shall occur daily when the ship is at sea and each time the ship is bunkering or de-bunkering.

The cumulative variations of the fuel tank level between two readings constitute the fuel consumed over the period. The period means the time between two port calls or time within a port.

For the fuel used during a period, the fuel type and the sulphur content need to be specified.

Fuel tank readings shall be carried out by appropriate methods such as automated systems, soundings and dip tapes.

The method for tank sounding and uncertainty associated shall be specified in the monitoring plan.

Where the amount of fuel uplift or the amount of fuel remaining in the tanks is determined in units of volume, expressed in litres, the company shall convert that amount from volume to mass by using actual density values. The company shall determine the actual density by using one of the following:

- on-board measurement systems;
- the density measured by the fuel supplier at fuel uplift and recorded on the fuel invoice or BDN;
- the density measured in a test analysis conducted in an accredited fuel test laboratory, where available.

The actual density shall be expressed in kg/l and determined for the applicable temperature for a specific measurement.

In cases for which actual density values are not available, a standard density factor for the relevant fuel type shall be applied once assessed by the verifier.

Method C: Flow meters for applicable combustion processes

This method is based on measured fuel flows on-board.

The data from all flow meters linked to relevant CO_2 emission sources shall be combined to determine all fuel consumption for a specific period.

The period means the time between two port calls or time within a port.

For the fuel used during a period, the fuel type and the sulphur content need to be monitored.

The calibration methods applied and the uncertainty associated with flow meters used shall be specified in the monitoring plan.

Where the amount of fuel consumed is determined in units of volume, expressed in litres, the company shall convert that amount from volume to mass by using actual density values. The company shall determine the actual density by using one of the following:

- on-board measurement systems;
- the density measured by the fuel supplier at fuel uplift and recorded on the fuel invoice or BDN.

The actual density shall be expressed in kg/l and determined for the applicable temperature for a specific measurement.

In cases for which actual density values are not available, a standard density factor for the relevant fuel type shall be applied once assessed by the verifier.

Method D: Direct CO_2 emissions measurement

The direct CO_2 emissions measurements may be used for voyages and for CO_2 emissions occurring in ports located in a Member State's jurisdiction.

CO_2 emitted shall include CO_2 emitted by main engines, auxiliary engines, gas turbines, boilers and inert gas generators.

For ships for which reporting is based on this method, the fuel consumption shall be calculated using the measured CO_2 emissions and the applicable emission factor of the relevant fuels.

This method is based on the determination of CO_2 emission flows in exhaust gas stacks (funnels) by multiplying the CO_2 concentration of the exhaust gas with the exhaust gas flow.

The calibration methods applied and the uncertainty associated with the devices used shall be specified in the monitoring plan.

IV.II. GUIDANCE/BEST PRACTICES DOCUMENT ON MONITORING AND REPORTING OF FUEL CONSUMPTION, CO2 EMISSIONS AND OTHER RELEVANT PARAMETERS PURSUANT TO REGULATION 2015/757 ON MONITORING, REPORTING AND VERIFICATION EMISSIONS FROM MARITIME TRANSPORT. [7]

From 1st January 2018 companies are required to collect and later report verified annual data on CO_2 emissions and other relevant information for ships over 5 000 gross tons on voyagesf rom and to EU ports. Furthermore, by 31 August 2017, for the ships concerned, companies have to submit to an accredited MRV shipping verifier a monitoring plan, consisting of complete and transparent documentation of the monitoring method and procedures to be applied for each of the ships under its responsibilities.

IV.II.I. Content of the monitoring plan

The monitoring plan shall consist of a complete and transparent documentation of the monitoring method for the ship concerned and shall contain at least the following elements:

(a) the identification and type of the ship, including its name, its IMO identification number, its port of registry or home port, and the name of the shipowner;

(b)the name of the company and the address, telephone and e-mail details of a contact person;

(c) a description of the following CO_2 emission sources on board the ship: main engines, auxiliary engines, gas turbines, boilers and inert gas generators, and the fuel types used;

(d) a description of the procedures, systems and responsibilities used to update the list of CO_2 emission sources over the reporting period;

(e)a description of the procedures used to monitor the completeness of the list of voyages;

(f) a description of the procedures for monitoring the fuel consumption of the ship, including:

(i)the method chosen from among those set out in Annex I for calculating the fuel consumption of each CO_2 emission source, including, where applicable, a description of the measuring equipment used,

(ii)the procedures for the measurement of fuel uplifts and fuel in tanks, a description of the measuring equipment used and the procedures for recording, retrieving, transmitting and storing information regarding measurements, as applicable,

(iii)the method chosen for the determination of density, where applicable,

(iv)a procedure to ensure that the total uncertainty of fuel measurements is consistent with the requirements of this Regulation, where possible referring to national laws, clauses in customer contracts or fuel supplier accuracy standards;

(g)single emission factors used for each fuel type, or in the case of alternative fuels, the methodologies for determining the emission factors, including the methodology for sampling, methods of analysis and a description of the laboratories used, with the ISO 17025 accreditation of those laboratories, if any;

(h) a description of the procedures used for determining activity data per voyage, including:

(i)the procedures, responsibilities and data sources for determining and recording the distance,

(ii)the procedures, responsibilities, formulae and data sources for determining and recording the cargo carried and the number of passengers, as applicable,

(iii) the procedures, responsibilities, formulae and data sources for determining and recording the time spent at sea between the port of departure and the port of arrival;

(i) a description of the method to be used to determine surrogate data for closing data gaps;

(j) a revision record sheet to record all the details of the revision history.

The monitoring plan may also contain information on the ice class of the ship and/or the procedures, responsibilities, formulae and data sources for determining and recording the distance travelled and the time spent at sea when navigating through ice.

Companies shall use standardised monitoring plans based on templates determined by the Commission by means of implementing acts.

IV.II.II. Content of the emissions report

From 2019, by 30 April of each year, companies shall submit to the Commission and to the authorities of the flag States concerned, an emissions report concerning the CO_2 emissions and other relevant information for the entire reporting period for each ship under their responsibility, which has been verified as satisfactory by a verifier .
Where there is a change of company, the new company shall ensure that each ship under its responsibility complies with the requirements of this Regulation in relation to the entire reporting period during which it takes responsibility for the ship concerned.
Companies shall include in the emissions report the following information:

(a) data identifying the ship and the company, including:
(i) name of the ship,
(ii) IMO identification number,
(iii) port of registry or home port,
(iv) ice class of the ship, if included in the monitoring plan,
(v) technical efficiency of the ship (the Energy Efficiency Design Index (EEDI) or the Estimated Index Value (EIV) in accordance with IMO Resolution MEPC.215 (63), where applicable),
(vi) name of the shipowner,
(vii) address of the shipowner and its principal place of business,
(viii) name of the company (if not the shipowner),

(ix) address of the company (if not the shipowner) and its principal place of business,
(x) address, telephone and e-mail details of a contact person;

(b) the identity of the verifier that assessed the emissions report;
(c) information on the monitoring method used and the related level of uncertainty;
(d) the results from annual monitoring of the parameters.

IV.II.III. Monitoring on a per-voyage basis

Based on the monitoring plan assessed in accordance with Article 13(1), for each ship arriving in or departing from, and for each voyage to or from, a port under a Member State's jurisdiction, companies shall monitor the following parameters:

(a) port of departure and port of arrival including the date and hour of departure and arrival;

(b) amount and emission factor for each type of fuel consumed in total;

(c) CO2 emitted;

(d) distance travelled;

(e) time spent at sea;

(f) cargo carried;

(g) transport work.

Companies may also monitor information relating to the ship's ice class and to navigation through ice, where applicable.

A company shall be exempt from the obligation to monitor the information referred above on a per-voyage basis in respect of a specified ship, if:

(a) all of the ship's voyages during the reporting period either start from or end at a port under the jurisdiction of a Member State; and

(b) the ship, according to its schedule, performs more than 300 voyages during the reporting period.

IV.II.IV. Monitoring on an annual basis

Based on the monitoring plan assessed in accordance with Article 13, for each ship and for each calendar year, companies shall monitor the following parameters:

(a) amount and emission factor for each type of fuel consumed in total;

(b) total aggregated CO_2 emitted within the scope of this Regulation;

(c) aggregated CO_2 emissions from all voyages between ports under a Member State's jurisdiction;

(d) aggregated CO_2 emissions from all voyages which departed from ports under a Member State's jurisdiction;

(e) aggregated CO_2 emissions from all voyages to ports under a Member State's jurisdiction;

(f) CO_2 emissions which occurred within ports under a Member State's jurisdiction at berth;

(g) total distance travelled;

(h) total time spent at sea;

(i) total transport work;

(j) average energy efficiency.

Companies may monitor information relating to the ship's ice class and to navigation through ice, where applicable. Companies may also monitor fuel consumed and CO_2 emitted, differentiating on the basis of other criteria defined in the monitoring plan.

IV.II.V. Technical efficiency of a ship

According to Article 11 (3) and 21 (2) of the MRV Shipping Regulation and to part A, point 6of the template for emissions reports, the technical efficiency of a ship is to be reported by using either the Energy Efficiency Design Index (EEDI) or the Estimated Index Value (EIV).

The attained EEDI is to be reported where required by and in accordance with MARPOL Annex VI, Regulations 19 and 20.

Only for ships not covered by the EEDI, the Estimated Index Value (EIV) has to be reported for ship types as listed in:

a) MEPC.231(65), paragraph 3: bulk carrier, gas carrier, tanker, container ship, general cargo ship, refrigerated cargo carrier, combination carrier, ro-ro cargo ship, ro-rocargo ship (vehicle), ro-ro passenger ship and LNG carrier.

b) MEPC.233(65), paragraph 5: cruise passenger ships having non-conventional propulsion, including diesel-electric propulsion, turbine propulsion, and hybrid propulsion systems.

For the ship type which is not covered by the above guidelines, it is not required to report EIV, as "Not applicable".

Companies are encouraged to report voluntary EEDI values, if available, instead of the EIV

Calculation of EIV

The formula for calculating the EIV value for each ship (excluding container ships and ro-ro cargo ships (vehicle carrier), ro-ro cargo ships, ro-ro passenger ships and LNG carriers) is as follows:

$$Estimated\ Index\ Value = 3.1144 \cdot \frac{190 \cdot \sum_{i=1}^{NME} P_{MEi} + 215 \cdot P_{AE}}{Capacity \cdot V_{ref}}$$

Specific formulae (and input parameters - PME(i) and PAE) for containerships and vehiclecarriers, ro-ro cargo ships, ro-ro passenger ships and LNG carriers are provided in MEPC.231(65).

For cruise passenger ships having non-conventional propulsion same information is provided in MEPC.233(65), remaining input parameters other than Capacity and Vref are provided in MEPC.1/Circ. 866.

Data should be taken from available documents. If available, the reference speed can be obtained from the power-speed curves produced following sea trials at the time of delivery.

These curves were submitted by the yard to the shipping company and they constitute an important document for the ship. Alternatively, data can potentially be obtained for vessels equipped with hull & fuel performance monitoring systems.

If no other values are available, the IHSF database should be used for EIV input parameters.

Verification

Verification of the reported technical efficiency should focus on the correct use of attained EEDI values or on the correct calculation of EIV values including plausibility checks of input values.

In case of no changes in EIV values compared to previous emissions report for a ship, results of verification of previous emissions reports should be considered by the verifiers to avoid repetition of verification activities.

IV.II.VI. *Determination of fuel consumption and CO_2 emissions*

IV.II.VI.I. *Fuel oil consumption*

The Master has ultimate responsibility for the monitoring of ship's bunker consumption and for reporting the data to the office as set by the company's procedures.

The Chief Engineer is responsible for the overall bunker operations, including the verification of bunker received, the sounding of the bunker tanks and calculation of the exact quantity of bunkers onboard.

IV.II.VI.II. *Fuel consumption "in port" and "at sea"*

The fuel consumption "in port" is the total amount of fuel from the time the ship arrives at first berth of a port and up to the time the ship leaves the last berth of the portwhere commercial cargo operations or embarkation/disembarkation of passenger took place.

The total fuel consumed "in port" can be:

• the difference between the fuel measured on board when the ship arrives at the first berth of a port and the fuel measured on board when the ship leaves the last berth of the port (eventual fuel bunkered during the stay in the port is not accounted for in this measurement) ; and

• when applicable, the fuel consumed while the ship was waiting at anchor or is carrying out ship-to-ship transfers within the port area

All other fuel consumption except the above should be considered as "at sea".

IV.II.VI.III. *Tanks sounding fuel oil measurement and monitoring*

Below is a generic guidance for fuel oil measurement through manual sounding/ ullage measurements. Depending on the situation onboard, it should be taken into account that notall ships may need to follow each step and the frequency of measurements provided below.

Frequency

The frequency of fuel tanks' stock takings through soundings/ ullages should occur:

For fuel monitoring method A (Annex I) :

a) Upon bunkering and de-bunkering

b) Upon arrival to the first berth of a port and before leaving the last berth of the port where commercial cargo operations or embarkation/ disembarkation of passengers took place prior to engaging on a voyage for a port outside the scope of the Regulation.

c) For ships in short and regular trades and for ships using shore power while at berth the measurements may take place either upon arrival at the first berth or before leaving the last berth.

d) Allocation of all fuel consumption (for each fuel type) not under the scope of the regulation is needed as the sum is to be subtracted from the amount provided in the Bunker Delivery Note (BDN)

Although Method A is based on fuel data from BDN, ships need to measure fuel in tanks to make the balance at the end of the voyage or the end of the monitoring period
For fuel monitoring method B (Annex I):

a) Upon bunkering and de-bunkering

b) Fuel tank readings for all bunker tanks onboard should occur daily when the ship is at sea. These could be on a daily basis at 12:00 noon time, the start/end of a canal crossing, a voyage interruption, etc.

c) While at sea passage prior entry and exit of a Sulphur Emission Control Area (SECA), if there is a fuel switch.

<u>Calculating the volume of bunker in each tank</u>

The ship specific sounding/ calibration tables produced by shipyard for each individual bunker tank should be used to determine the volume of bunker in each tank taking into account the trim and list of the vessel.

ASTM D 1250-80 Standard Guide for Petroleum Measurement, table 54B, or equivalent tables or a substantiated software for temperature and atmospheric pressure corrections of density and mass calculations should be used.

The software could additionally be supported by dedicated ship specific software for trim, list and temperature corrections is available on board.

<u>Density</u>

Density values to be used could be one of the following:

(a) on-board measurement systems;

(b) the density measured by the fuel supplier at fuel bunkering and recorded on BDN;

(c) the density measured in a test analysis conducted in an accredited fuel test laboratory, where available.

The source of density values should be stated at all times. However, the fuel oil volumes recorded onboard after each monitoring may always be related to the standard temperature of 15oC.

To cater for most practical handling onboard with the density issue – as an alternative to above- volume to mass conversion – may be done using standard conversion factors. The company may use bespoke conversion factors for the entire reporting period subject to criteria for establishing these have met the agreement of the verifier. The company may also use the following standard conversion factors:

• 0.96 when using RME180, RMG 180/380/500/700 or RMK 380/500/700

• 0.88 when using MGO/MDO

These standard conversion factors derive from ISO 8217 Fuel Standard figures after having been corrected with ASTM D1250 density temperature variation tables (using 60°C - 80°C for IFO/HFO and 40°C for MDO/MGO) and apply regardless of whether the volume measurements are made in the bunker tanks or at a volume flowmeter placed between the service tank and the engine inlet.

<u>Gauging equipment</u>

In general, there are several methods of gauging fuel tanks, e.g., manual soundings, gauges with audible noise when an oil interface is reached, pressure transducers, radar and so forth; each ship will adapt this part for description according to the equipment they use.

As back-up for fixed installed tank sounding/ gauging equipment, the method of determination of a tank's sounding or ullage is suggested to be manual soundings. The tape or measuring device is to be graduated in feet, inches and fractions of an inch; or meters, centimetres, and millimetres.

Tapes which have been kinked or spliced or which contain illegible markings should not be used.

IV.II.VI.IV. <u>Continuous fuel oil monitoring</u>

This procedure is for ships using flowmeters on consumers (e.g. main engines, auxiliary diesels, inert gas generators, boilers, etc.).

The data from all flow meters linked to fuel consumers minus the data from all flow meters at the return lines from the same consumers (if applicable) should be combined to determine fuel consumption over a period.

Regardless if the fuel measurements are automatically recorded and transmitted, it is a good practice for ships engaged in long voyages when at sea to record daily measurements in the Engine Logbook. Depending on type of ship operation the master, chief engineer or the operator may follow other practice as per company SMS.

The validity of fuel flowmeters should be compared on a periodic basis through comparison with the fuel figures that derive from flowmeters and tank soundings. The ship operator's PMS should provide guidance on comparison frequency.

To ensure proper readings, fuel flowmeters onboard should be calibrated as per maker's recommendations or based on the ship's operational experience if flow meter is maintaining operational accuracy within manufactures suggested tolerances. Any records of manufacturer calibration should be maintained onboard and captured within the PMS onboard.

In the event that a fuel measurement cannot be made due to failure of a flow metering device the daily fuel consumption should be determined by utilising the tank soundings method.

Volume flowmeter

The amount of fuel consumed is determined in units of volume, expressed in litres, and it is converted to mass by using the density values corrected for the applicable temperature

Density values to be used should originate from BDN or provided through a fuel test analysis conducted in an accredited fuel test laboratory. Source of density values should be stated at all times.

ASTM D 1250-80 table 54B or equivalent tables or a substantiated software for temperature corrections of density should be used.

Temperature to be used for density corrections should be the fuel temperature at the flowmeters.

Mass flowmeters

The mass flow meters measures directly the mass flow rate of the fuel and eliminates the need for further mathematical calculations to derive the mass of fuel consumed.

IV.II.VI.V. LNG consumption – on-board monitoring of boil off gas (BoG)

Below are listed best practices to the verifier and the company for the on-onboard monitoring of boil off gas (BoG) and recording of data for the purpose of monitoring of fuel consumption required by the MRV Shipping Regulation.

As required by the MRV Shipping Regulation, Annex-1 (Methods for monitoring CO2 emissions), the company defines in the monitoring plan which monitoring method is to be used to calculate fuel consumption for each ship under its responsibility and ensure that once the method has been chosen, it is consistently applied. However, the `Method A` states that "This method shall not be used when BDN are not available on board ships, especially when cargo is used as a fuel, for example, liquefied natural gas (LNG) boil-off "

Since BDN cannot be used for the BoG, it is important for the verifier and the company to ensure that BoG measurement, calculation and documentation is in accordance with in fact use and is accurate, relevant and consistent.

LNG tankers are designed to carry natural gas in liquid form at a temperature of about - 163°C, close to the vaporization temperature. Despite that tank insulation is designed to limit the admission of external heat, even a small amount of it will cause slight evaporation of the cargo. This natural evaporation, known as “natural boil-off” (NBoG) is unavoidable and has to be removed from the tanks in order to control / limit the cargo tank pressure. Typical values are about 0.15%/day and below, recent projected LNG carriers are offered with a NBoR close to or even beneath 0.1%22.

Where insufficient NBOG volumes are available for propulsion, forced vaporization of LNG can be effected or otherwise liquid fuel (HFO /MDO/MGO) can supplement the additional energy demand. The force vaporized LNG is called Forced Boil Of Gas (FBOG). The NBOG and the FBOG will be collectively called BOG in this paper.

Boil-off gas (BoG) handling systems (known as Gas Management Systems) are typically used onboard LNG carriers as a means of pressure and temperature control. BoG is sent to the engine room via gas heaters by low capacity compressors and is burned by the main boilers or nowadays by dual fuel diesel engines as fuel.

On steam turbine powered vessels, the main boilers are capable of operating under different fuel combustion modes such as exclusively BoG mode (NBoG or NBoG + FBoG), combined BoG and fuel oil mode, and exclusively fuel oil mode. Although steam turbine systems have been the main form of propulsion used onboard LNG carriers and still comprise a large percentage of the operating LNG fleet, diesel engines capable of using BoG as fuel have become a preferred solution due to their higher operating efficiencies.

LNG carriers with diesel engines are required to have a “Gas Combustion Unit” onboard. This GCU acts as a secondary means of controlling the tank pressure, in particular to cater for certain conditions like bad weather causing excessive NBoG generation, the temporary inability of the engines to burn gas or at engines’ low load operation lower than what is required to consume the available NBOG for propulsion and other services or when the vessel is idle. The flow to the GCU is to be included in the amount “consumed”. In general, GCU’s are equipped with flowmeters. However, there might be other uses for the GCU which may cause conflicts, e.g. when preparing for dry-dock, contaminated BoG / inert gas mixture is disposed off in this unit.

On the Steam LNG Carriers if the required energy for propulsion and other services drops below the energy available by the BOG, the main boilers continue to consume the available BOG and the excess steam generated is dumped directly into the condenser.

The natural Boil-off rate (BoR) is the amount of liquid that is evaporating from a cargo and expressed in % of total liquid volume per unit time.

It shall be noted that the MRV Shipping Regulation requires the reporting for LNG carries has to be done as follows:

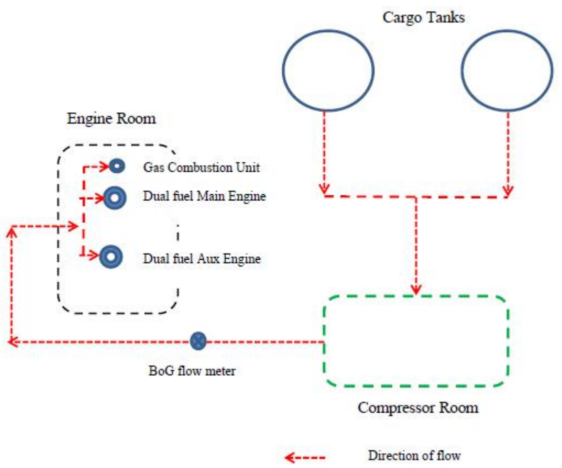
- LNG cargo carried onboard to be reported in VOLUME units

- LNG consumed onboard as fuel to be reported in MASS units

It should be noted that a number of LNG carriers are equipped with re-liquefaction systems which depending on the capacity can partially or fully re-liquefy the NBOG and send it back to the cargo tanks.

Usually the Master has overall responsibility for the monitoring of ship's bunker consumption and BoG use/ consumption. This will be described in detail in company´s management procedures.

The following diagram shows a generic ships BoG fuel oil system.



IV.II.VI.VI. BoG measurement and monitoring

The BoG can be measured by calculating the total LNG consumed for a voyage by custody transfer measurement system (CTMS) or by flow meters (onboard).

CTMS systems are the predominant systems available for all LNG carriers. They are used for determining the amount of cargo loaded or discharged and they have universally accepted with commercial relevance and are typically third-party verified.

α) Calculating BoG quantity by CTMS

Cargo consumed on the passage is calculated by using the "CTMS closing" (final volume on board at the loading terminal upon completion of loading) and "CTMS opening" (total volume upon arrival at the discharge terminal just before commencement of discharging) figures.

CTMS measures the volume of cargo in the tanks and further calculations convert the volume to weight / mass at the reference temperature. Therefore, the BoG is calculated as the difference between "CTMS closing" figure at the loading port and the "CTMS opening" figure at the discharging port.

In case of cargo discharge at several locations in a port of call, the discharged volumes have to be aggregated. In case of further discharges in other ports of call (in other words: during the subsequent voyages), the volumes discharged in these ports have to be added to the discharged volume, until new cargo is loaded.

On the ballast passage LNG carriers may maintain a comparatively small amount of LNG called "the heel" which can be used as fuel and/or for maintaining the cargo tanks in cold state ready to be loaded at the next loading port, using the same methodology as for the laden passage consumption.

b) Calculating BoG quantity by flow meters

If it is chosen to measure the BoG with flow meters instead of measuring through the CTMS, the BoG is measured either in volume and then converted to mass using appropriate density, pressure and temperature corrections or measured directly in mass (coriolis type flow meters).

Flow meters are typically installed on the BoG supply lines to the main boilers, diesel engines and the GCU as the case may be. The sum of all such flow meters determines the total BoG consumed.

In cases where the BoG is measured via onboard volume flow meters, the method to convert volume to weight (e.g. using the composition of the cargo at load port for deriving its density and converting volume to mass) will be decided by the company and described in the company's management procedures. Bases on this method, the BoG used to fuel the ship during the voyage will be determined.

Shipping companies may determine the LNG vapour density for onboard flow meters using standard temperature of 15°C and calculation based upon ideal gas laws.

The amount of BoG consumed at berth may be derived by the flow meters installed on the piping supplying gas to the consumers (engines, boilers, etc.).

However, for the consumption in ports, the CTMS (opening and closing) might not in all cases reveal the full picture. Therefore, flow meters are the favourable alternative for port consumption. In particular, the shore meters of the vapour return line are useful to mention in this context as they are a commercial method which is applied, accurate and typically verified by a specialized 3rd party. Usually, the commercial calculation process does explicitly calculate the amount (the balance) consumed by the ship during the cargo operations.

<u>Accuracy and calibration of measuring equipment</u>

All measuring equipment used for the monitoring should be maintained in good order and calibrated or certified for "fitness of purpose" in accordance with the maker's guidance. Further information on maintenance procedures or in correlation with the PMS should be provided from the shipping company.

A copy of maintenance records and/ or the calibration certificate should be kept on board.

Other relevant considerations

Existing EU legislation, namely the Directive (EU) 2016/802 relating to a reduction in the sulphur content of certain liquid fuels and more specifically the Commission Decision 2010/769/EU allow LNG carriers to use a specified BoG mixture as an equivalent abatement method to the low sulphur content oil-based fuels, i.e. for sulphur compliance reasons. For this purpose, it is required by Article 4 of Commission Decision 2010/769/EU that these ships are equipped with continuous monitoring and metering of the boil-off gas and marine fuel (i.e. pilot fuel) consumption.

More recently, the European Commission and EU Member States (through the Committee on Safe Seas and the Prevention of Pollution from Ships (COSS)) agreed, under certain circumstances (ship-specific design, operational profile & predefined BoG mixtures) on an extension to this equivalence also for propulsion purposes while sailing in the SECA.

Thus, it should be assumed that all the LNG carriers that would trade in the EU and planning to use BoG and marine fuel mixture as an abatement method, are already equipped with such continuous measuring/ metering devices plus related recording logs.

IV.II.VI.VII. Calculation of CO_2 emissions (article 9)

For the purposes of calculating CO_2 emissions companies shall apply the following formula:

Fuel consumption × emission factor

Fuel consumption shall include fuel consumed by main engines, auxiliary engines, gas turbines, boilers and inert gas generators.

Fuel consumption within ports at berth shall be calculated separately.

The following default values for emission factors for fuels used on board shall be applied:

Type of fuel	Reference	Emission factor (t-CO2/t-fuel)
1.Diesel/Gas oil	ISO 8217 Grades DMX through DMB	3,206
2.Light fuel oil (LFO)	ISO 8217 Grades RMA through RMD	3,151
3.Heavy fuel oil (HFO)	ISO 8217 Grades RME through RMK	3,114
4.Liquefied petroleum gas (LPG)	Propane	3,000
	Butane	3,030
5.Liquefied natural gas (LNG)		2,750
6.Methanol		1,375
7.Ethanol		1,913

Appropriate emission factors shall be applied for biofuels, alternative non-fossil fuels and other fuels for which no default values are specified

IV.II.VI.VIII. Determination of distance travelled and time spent at sea

For these two parameters following best practices are recommended:

- Distance travelled should be determined as distance over ground to follow the approach decided at IMO's MEPC 70.
- Should the vessel be adrift (i.e. while waiting for a berth) the distance should be included as the vessel is underway. Even if the main propulsion is temporarily not required, there will be still auxiliary generators and boilers in operation.
- Distances made for the purposes of tank cleaning operations should be included as the vessel is underway.
- Ship to Ship Transfer within defined limits of a port is considered as a port call.
- Unforeseen voyage deviations such as SAR (Search and Rescue), disembarkation of a sick crew member, etc. should not result in an additional administrative burden for the carrier and verifier. Therefore it should be reported on a voluntary basis only.
- Since the EU Regulation stipulates that “time spent at sea” is to be calculated based on port departure and arrival information, it is recommended to use the arrival at the first berth and the departure of the last berth in a port where cargo operations have been conducted.
- Standard voyage distances and the use of scheduled time between scheduled port of departure and scheduled port of

arrival for the monitoring of time spent at sea should be only considered for short fixed voyages such as for ro-ro/ ro-pax vessels. However, the usage of standard short voyages cannot be based exclusively on VTS distance, since distances and time spend at sea could be also subject to many factors such as avoiding shallow waters or an ECA transit.

- Given a high number of deviation scenarios, applying a “most direct route” (standard distance and time spent at sea) should be strongly discouraged, but could be used in order to fill data gaps subject to final approval by the verifier.
- It should be borne in mind that any correction factors have to be defendable and must be justifiable towards the verifier. There is a risk of wrongly estimating distances, (either as under or over estimation). It can create uncertainty in comparison to truly measured distances over ground and may result in an uneven, distorted playing field.

IV.II.VII. Determination of cargo carried

Parameters for cargo carried Parameters for 'cargo carried' are specified for 14 ship types and a category 'others' (in Annex II to the MRV Shipping Regulation, as amended, and in Commission Implementing Regulation (EU) 2016/1928). Furthermore, the emissions report template as specified by Commission Implementing Regulation (EU) 2016/1927 allows for the reporting of additional parameters on a voluntary basis.

IV.III. EXISTING MRV PROGRAMS AND TOOLS BEFORE THE IMPLEMATATION OF THE MRV REGULATION [8], [9],[14]

Ship monitoring, reporting and verification (MRV) programs are not new, in principle. Shippers track vessel criteria that relates to safety as well as environmental and financial performance. As such, vessel fuel consumption, as a key operational expense, is tracked to varying degree by all shipping companies.

According to the final report with title “ Maritime transport greenhouse gas data collection and management / MRV Procedures” (11-12-2014) by Cathrine Sachweh, Julia Larkin, Rob Winkel, Jasper Deman (Ecofys) Bryan McEwen (SNC Lavalin) Chris Peddie-Burch, Grant Turtle, Kevin Williams (SFW) that aimed to support the implementation of the proposed EU MRV Regulation for the monitoring of CO2 emissions from maritime transport, a number of programs already existed that aimed to monitor emissions and efficiency.

The following section describes several of those preexisting marine MRV programs: public programs with a central authority, private programs run by a consulting group and internal programs run by a shipping company.

Most of these programs include use of a CO2 indicator. The information on the different programs has been compiled using publicly available information and information requested from programs by means of a survey (FRAM, Clean Cargo Working Group) and interviews (Norden). It should be noted that some of the programs assessed provide an extensive amount of publicly available information, where other programs either do not disclose detailed information or the information is simply not present in the first place.

IV.III.I. Existing MRV programs and tools

1. Clean Cargo Working Group (CCWG)

The Clean Cargo Working Group (CCWG) is a business-to-business leadership initiative involving major brands, cargo carriers, and freight forwarders dedicated to reducing the environmental impacts of global goods transportation and promoting responsible shipping. Today, CCWG tools represent the industry standard for measuring and reporting ocean carriers’ environmental performance on carbon dioxide emissions.

The CCWG runs a voluntary MRV program for CO2 emissions from global containerized shipping. CCWG has developed the CCWG CO2 methodology on how to standardise, report and calculate CO2 emissions. The CCWG measures CO2 emissions by first calculating emission factors (emissions per unit of cargo capacity) which are then used to calculate CO2 emissions for both carriers and shipping customers. Clean Cargo carriers report on the following data for each vessel annually (BSR, 2012):

- Nominal capacity in 20-foot equivalent container units (TEUs)
- Number of reefer plugs (plugs for refrigerator containers)
- Distance sailed
- Fuel consumed (HFO and MDO/MGO reported separately)
- Timeframe of data.

The Clean Cargo Performance Metrics Tool uses this information and the IMO emission factor for HFO of 3114.4g CO_2 per kg fuel to calculate vessel CO_2 emissions per capacity and distance sailed:

Total kg fuel consumed for containers, multiplied by 3114.4g CO_2/kg fuel, divided by the product of [maximum nominal TEU capacity * total distance sailed]

Every year CCWG carriers report on vessel-specific environmental performance data to BSR (the secretariat of CCWG), using a standard reporting template and guidance methodologies, including the CCWG CO_2 Carbon Emissions Accounting Methodology. Each carrier also undertakes third-party verification of their reporting system using the CCWG Procedure and guidance for verifying CO_2 and SOx data.1 BSR provides the aggregated data to shipping customers that are members of CCWG, via individualized carrier scorecards.

The 2017 annual index is derived from emissions reported by over 3,200 ships, calculated from 22 of the world's leading ocean container carriers, who collectively represent around 87 percent of ocean container capacity worldwide. A complete list of CCWG members can be found on our web page.These results are based on primary data from vessels operating during the calendar year.

The 2017 annual reporting indicates that average CO_2 emissions per container per kilometer for global ocean transportation routes were reduced by 2.4 percent from 2015 to 2016.

2. Norden's Masters Operational Environmental Performance System (MOEPS)

Shipping company Norden operates a software/server based Monitoring and Reporting system called Masters Operational Environmental Performance System (MOEPS). MOEPS is a comprehensive communication tool, where almost all information is integrated for the benefit of the primary users, being the ships Master and the vessel operator. The focus of MOEPS is to optimize Fuel consumption and to ensure primary users focus their time on non-administrative tasks. It generates input to "Right Steaming" and monitors adherence to speed and consumption instructions.

Ships upload all relevant operational data daily, including fuel consumption, position and speed via email or broadband. Figure 2 displays the information exchange of the MOEPS system.

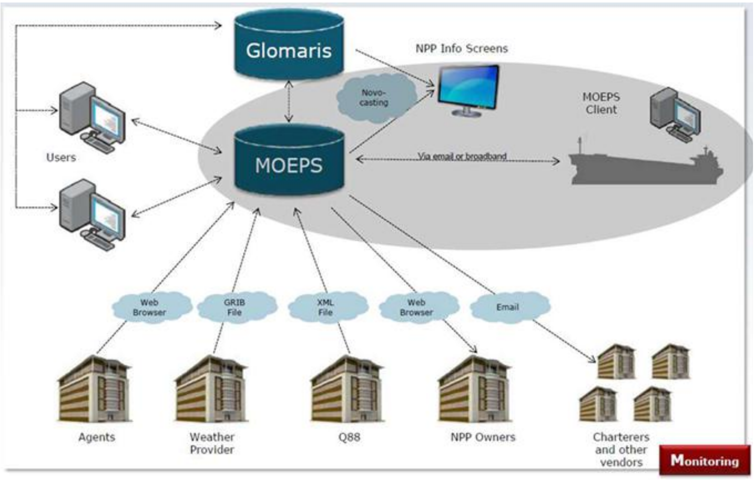


Figure 2: MOEPS information exchange overview (source: Norden)

MOEPS was implemented in Q4 of 2009.

3. FRAM program

The FRAM program in Norway is a voluntary vessel reporting initiative that was initiated by several organizations including the World Wildlife Fund (WWF), BW Gas, Grieg Star Shipping, Welhelmsen ASA, Solvang Shipping, Klaveness, DNV and the Norwegian Shipping Association. Since inception approximately a year and a half ago FRAM has received government funding to further develop the program and additional shippers have been invited to join. Program reporting includes fuel consumption and absolute CO_2 emissions, including two measures for efficiency: mass of CO_2 per unit of work performed (i.e. transport efficiency) and per nautical mile sailed (i.e. vessel efficiency). Verification of reports is included, following ISO 14064 guidelines (although self-verification is permitted during year 1).

4.French Transport Code

As of 1 October 2013, all organisations providing transport services in France are required by law to inform their clients of the carbon footprint of their journeys. The Regulation applies to transport services for passengers, goods or moving purposes, carried out using one or several means of transport, departing from or travelling to a location in France, with the exception of transport services organised by public or private persons on their own behalf. The Regulation includes shipping by sea. Different methods with an increasing level of precision are described for estimating emissions for a service (MEDDTL, 2012):

• Level 1: emissions are determined using parameters published by the ministry of transport: a default emission factor (e.g. tCO_2/tonne-km) for a particular ship type is multiplied by the amount of payload carried and distance travelled for a particular service (e.g. transporting 20 containers from Le Havre to Tokyo).
• Level 2: emissions are determined using average value of the whole activity of the transport operator. This approach is only described for regular seagoing service transporting road vehicles. For such services the trip distance is assumed to be rather constant: the average emissions per unit of cargo per voyage (e.g. tCO_2/tonne-voyage) is first calculated. That emission factor is then multiplied by the amount of cargo carried for a particular service (e.g. a 35 ton truck).
• Level 3: emissions are determined using average value based on each specific activity of the transport operator. An annual average emission factor (e.g. tCO_2/tonne-km) is first calculated based on annual fuel consumption per type, emission factor per fuel type (tCO_2/kg fuel), cargo carried and distance travelled. That emission factor is then multiplied by the amount of payload carried and distance travelled for a particular service.
• Level 4: emissions are determined based on data issued by real time operating reports. This method is not specified explicitly for shipping by sea. It would consist of calculating

the emissions for a specific voyage based on actual fuel consumption on that voyage.
Depending on the type of payload, the unit of payload can be tonne, TEU or passenger. Distance can be the actual distance travelled or a standard distance between two ports. The Regulation stipulates that the breakdown of emissions over goods and passengers must take place according to the number of decks.

5 Germanischer Lloyd - Environmental Passport

The "Environmental Passport – Operation" service from GL certifies a ship's emission inventory for a one-year reporting period (GL, 2013). The following parameters are recorded for every voyage leg for the determination of a ship's CO2 emissions:

• Total fuel consumption (i.e. main engine[s], auxiliary engine[s], boiler[s]) including the respective fuel type.
• Time and geographical position for start and completion of each fuel change over beginning as well as end of voyage legs.
• Amount of transported cargo in the appropriate unit depending on ship type and purpose, (e.g. cargo mass, lane meters, pax, TEU, volume).
• Distance sailed.

Emission data is accumulated during voyages and consolidated over the reporting period. The data is verified by GL. Procedures and related requirements are documented in the GL Environmental Service System guidelines (GL, 2012). GL's Environmental Passport – Operation summarises emissions to water and air based on predefined categories including CO2, SOx, NOx and refrigerant releases emitted to air, ballast water, garbage and bilge water into the sea. The Environmental Passport – Operation covers the respective vessel's worldwide operation and also includes computation of the IMO Energy Efficiency Operational Indicator (EEOI).

6. Carbon Positive Programme for Ships (CPPS)

Carbon Positive developed a commercial MRV system applicable to all vessels. The MRV system assists the operator to monitor its fuel consumption and manage its carbon emissions. The Member feeds on a daily basis the (member-only) online platform according to the procedure described in the Monitoring Plan. The Data entry is automated minimizing administrative effort. The system also monitors all energy efficiency data. An emission report can be issued automatically any time the Member requests it. Carbon Positive also offers review and an optional third-party verification.

The MRV system follows a set of official international guidelines and requirements such as: the IMO's guidelines for monitoring of carbon emissions, the Intergovernmental Panel on Climate Change (IPCC) guidelines for monitoring and reporting of GHG and the verification requirements of the ISO 14064

IV.III.II. Comparison of preexisting marine MRV programs to the EU MRV Regulation

The overview shows that:
• None of the programs requires monitoring of fuel consumption per voyage. An exception is the GL Environmental Service System. CCWG, Norden and FRAM all have a global scope and do not require monitoring on a per voyage basis. The French program does require emissions reporting on a per-voyage basis and covers only voyages to and from France. That program does, however, not require monitoring of per voyage fuel use, but uses default or annual average factors.
• Like the EU MRV Regulation, all programs request information on the distance travelled.
• Not all programs request reporting of cargo. CCWG requests cargo capacity. Norden and the French initiative do use details of cargo, but these are not made public. FRAM requests cargo, but companies can choose to report transport work instead. This is similar to the EU MRV Regulation, which does require the monitoring, but not the reporting of cargo information.
• Similar to the EU MRV Regulation, all programs make use, or will make use of digital calculation or reporting tools.

IV.IV. TEMPLATES FOR MONITORING PLANS, EMISSIONS REPORTS AND DOCUMENTS OF COMPLIANCE PURSUANT TO REGULATION (EU) 2015/757 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL ON MONITORING, REPORTING AND VERIFICATION OF CARBON DIOXIDE EMISSIONS FROM MARITIME TRANSPORT. [5],[6]

Commission Implementing Regulation (EU) 2016/1927 of 4 November 2016 on templates for monitoring plans, emissions reports and documents of compliance pursuant to Regulation (EU) 2015/757 of the European Parliament and of the Council on monitoring, reporting and verification of carbon dioxide emissions from maritime transport, lays down templates and technical rules for the submission of monitoring plans, emissions reports and documents of compliance pursuant to Regulation (EU) 2015/757.

Companies shall draw up the monitoring plan referred to in Article 6 of Regulation (EU) 2015/757 using a template corresponding to the model set out in Annex I of the Commission Implementing Regulation (EU) 2016/1927.

Companies may split the monitoring plan into a company-specific part and a ship-specific part, provided that all elements set out in Annex I are covered. The information contained in the company-specific part, which may include Tables B.2, B.5, D, E and F.1 of Annex I, shall be applicable to each of the ships for which the company is to submit a monitoring plan pursuant to Article 6 of Regulation (EU) 2015/757.

The European Maritime Safety Agency (EMSA) has developed a new module in THETIS, namely THETIS-MRV, enabling companies responsible for the operation of large ships using EU ports to report their CO2 emissions under the Regulation (EU) 2015/757 on Monitoring, Reporting and Verification of CO2 from marine transport.

For the purposes of submitting the emissions report pursuant to Article 11(1) of Regulation (EU) 2015/757, companies shall use the electronic version of the template available in the Thetis MRV automated Union information system operated by the European Maritime Safety Agency.

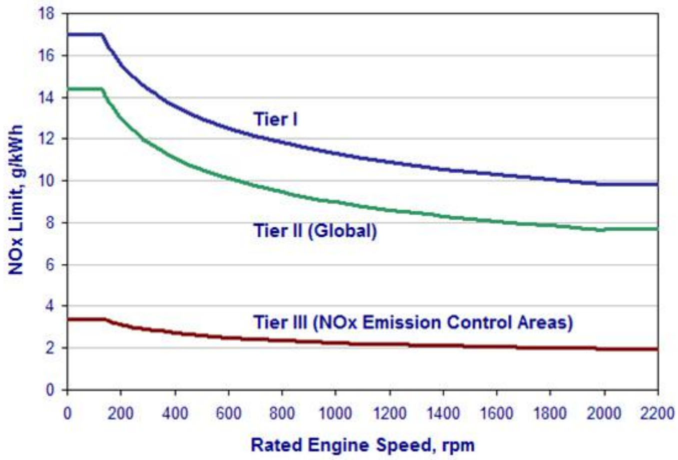
Through this web-based application all relevant parties foreseen by the Regulation can fulfil their monitoring and reporting obligations in a centralized and harmonised way.

THETIS-MRV includes a mandatory and a voluntary module: through the mandatory module, companies will generate Emission Reports which will then be assessed by Verifiers who will issue a Document of Compliance in system; through the voluntary module, companies may draft their monitoring plans and the system will make them available for verifier' assessment.

The system is available from 7 August 2017 and can be reached at https://mrv.emsa.europa.eu

V. AVAILABLE TECHNOLOGIES TO MEET MARPOL NOX TIER III REGULATION. [10],[11]

The IMO NOx-emission limits apply to diesel engines and depend on an engine's maximum operating speed (n, rpm), as presented in the table below. Tier I and Tier II are global requirements, whereas Tier III standards only apply to current existing Emission Control Areas (ECAs) for NOx (North American and US Caribbean Sea).



When the global Tier II limits came into force in 2011, engine-makers were able to tune the engines to comply with these new emissions limits. Tier III poses a challenge to engine designers, as tuning is not an option anymore and they need to apply NOx-reduction measures using other engine technologies.

To comply with this Tier III requirements ships shall have to be installed or retrofitted with equipment/systems which can reduce NOx below Tier III standards.

<u>The science of NOx</u>

The formation of NOx is complex. NOx is the collective term for Nitrogen dioxide (NO2) and Nitrous Oxide (NO). Nitrous Oxide is not NOx.

Nitrogen is a natural element in the atmosphere and is also found in the chemical structure of some fuels. During the fuel combustion process, NOx is formed in the cylinder in three ways:

– thermal formation, as a result of the reaction between atmospheric nitrogen and oxygen at high temperatures

– fuel formation, as a result of the reaction between nitrogen in the fuel and oxygen

– prompt formation, as a result of complex reactions with hydrocarbons and atmospheric nitrogen.

NOx is formed both at the initial stage of combustion in very high temperatures and later in the combustion process after a longer dwell time in the combustion chamber. Therefore, the formation of NOx requires both high temperatures and exposure time.

The major component of NOx on exit from the ship is nitric oxide,which readily oxidises in the atmosphere.

The proportion of nitric oxide attributable to thermal and fuel formation depends on the combustion conditions, which in turn are determined by the combustion unit type, configuration and operation, together with the fuel's grade and composition.

Prompt formation can exceed thermal formation under certain conditions where combustion temperatures are low, residence time is short and combustion conditions are fuel-rich.

Lowering the temperature of the combustion process reduces NOx but also reduces engine efficiency. Theoretical ideal heat engine efficiency is represented by the Carnot cycle, where heat efficiency is a function of the ratio maximum temperature to minimum temperature. Marine engines are not Carnot engines but efficiency is still related to the temperature differential across the cycle. Reducing the compression ratio by adjusting engine valve opening and closing, adding water to fuel or charge air or applying high-pressure super charging can reduce maximum combustion temperature. Lower combustion temperatures and lower combustion, atmospheric oxygen and nitrogen levels are the main approaches to reducing NOx emissions.

Mentioned below are technologies available to meet this criteria.

V.I. Primary compliance techniques for NOx:

V.I.I. Use of Low Pressure Gas Engines :

New marine engines using low pressure LNG as marine fuel will have greater importance in meeting Tier III standards. Wartsila has developed 2-stroke DF technology engine which makes use of low pressure LNG as fuel. It is based on lean-burn principle (relatively high air/fuel ratio), in which, the pre-mixed air/fuel charge is ignited by pilot fuel. One of the most important aspects of this engine is that the emission are below NOx Tier limit, and this is achieved without use of exhaust gas treatment system.

V.I.II. Exhaust Gas Recirculation (EGR) :

In this technology, part of the exhaust gas after turbocharger is recirculated to scavange receiver after passing it through the scrubber (exhaust gas washing) unit. Around 50-60% NOx reduction from tier I is claimed by making use of EGR. However discharge of cleaning water requires treatment like purification and separating exhaust gas cleaning sludge. As some countries are against discharge of this water, re-using this water poses corrosion problem.

NOx reduction takes place due to reduction in excess air (oxygen content) used for combustion, addition of CO_2 and water vapour reduces peak temperatures as both have higher specific heat than air.

EGR system along with combination of one of the technologies such as altered (delayed) injection method, new design fuel valve, common rail injection principle, electronic engines , Scavange Air Moisturizing, can be used to comply with Tier III standards.

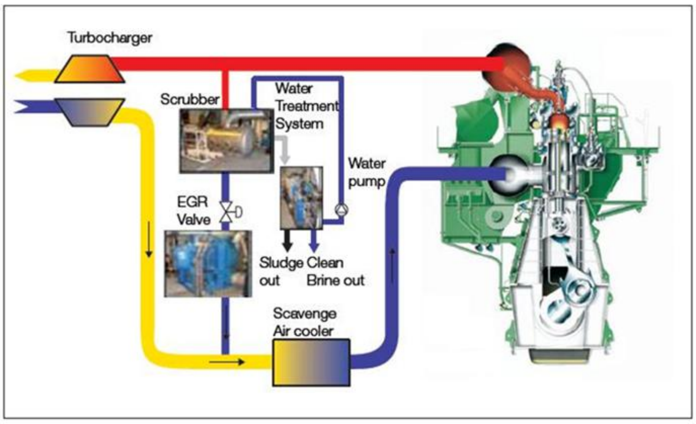


Image credits: Greenship.org

EGR systems can cause higher CO and PM emissions. CO emissions can be controlled by adding water to the fuel. However, adding water can reduce fuel efficiency and increase PM. Increasing turbocharger and fuel injection pressure can help to reduce the PM emissions.

There is a balance to be struck between EGR ratio and water addition to achieve an optimum balancebetween NOx, CO, PM and fuel efficiency.

V.I.III. Advanced fuel injection

In the longer term, the most promising primary NOx compliance option is advanced fuel injection using split or pulsed injection to control placement of fuel and the combustion characteristics within the cylinder. This technology is not available for marine engines yet but indicates future possibilities; it is already widely used in automotive engines.

Advanced fuel injection allows better control of cylinder pressures and heat release rates, establishing separate heat release stages so that cylinder temperatures and NOx formation are reduced. It may be used with a simple EGR system to achieve Tier III compliance. It is also technically possible that advanced fuel injection could achieve Tier III with no EGR or secondary exhaust treatment device.

V.I.IV. Fuel emulsification

Fuel emulsification has been recognised as an effective way of reducing NOx emissions for many years. Forming a stable and homogeneous emulsion can be challenging (particularly with distillate fuels) but it can be done. While achieving Tier III compliance using emulsification alone is proving to be challenging, it could be used with other techniques such as mild EGR or high-pressure super charging to achieve Tier III.

Given that emulsification systems affect the composition of fuel it is important to ensure that the resulting emulsified mixture is suitable for combustion machinery and that measures are in place to prevent the emulsification system exceeding the allowable fuel parameters for machinery.

V.I.V. High-pressure supercharging

Since combustion temperatures are related to the compression ratio of internal combustion engines, reducing this compression ratio can lower temperature and reduce NOx. This can be achieved by high-pressure supercharging using multi-stage turbochargers and by applying the Miller thermal cycle. In a Miller engine, the air inlet valves remain open for much longer than in a Diesel or Otto engine, with the result that typically only 70-80% of the upward piston stroke is compressing the charge air or pre-mixed charge air and fuel. While this is unlikely to achieve Tier III emissions compliance by itself, it can be used in conjunction with other techniques.

Although high-pressure supercharging improves emissions performance, it has high energy demand. If using turbochargers, this will significantly reduce the energy which is available for waste heat recovery systems. This is potentially quite important for ships with a high heating load. Clearly the supercharging system will be more complex and more expensive, particularly where multi-stage devices are used and these will require more complex charge air cooling arrangements. If the compression ratio is lowered too much, there may be problems with engine operability.

This method along with Direct Water injection (DWI) Principle and other methods such as fuel water emulsion can bring NOx well below Tier III standards.

V.II. Secondary compliance techniques for NOx

Primary techniques, such as using alternative fuels, have significant additional engineering requirements for safe storage, handling and use of fuels, while others can reduce engine efficiency. Secondary techniques are therefore potentially very attractive in avoiding engine efficiency penalties and the complexities of designing and installing an alternative fuels package.

V.II.I. Selective Catalytic Reduction (SCR)

In this system, urea or ammonia is injected in the exhaust gas before passing it through a unit, which consists of special catalyst layer, at a temperature between 300 and 400 Deg C. Chemical reaction between Urea/ammonia and NOx in exhaust gases reduces NOx (NO and NO_2) to N_2. SCR unit is installed between the exhaust manifold/receiver and the turbocharger.

High efficiency turbocharger is required for this system as there is pressure drop across SCR Reactor. Engine load should be 40% and above, as NOx is reduced to N2 within specific temperature window (300-400 Deg C).

If temperature is above 400 Deg C, ammonia will burn rather than reacting with NOx which will lead the system to be ineffective. If the temperature is below 270 Deg C, the reaction rate will be low and the ammonium sulphates formed will destroy the catalyst.

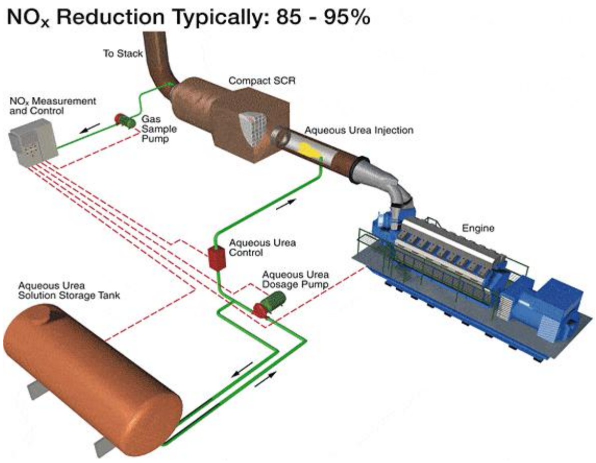


Image credits: vikingline.com

- Some B&W engine uses DeNOx or SiNOx system using SCR technology.
- Some Wartsila engines also has NOR (NOx Reduction) system that uses SCR technology.

Selective catalytic reduction (SCR) is the technology with the highest capability to reduce NOx emissions and comply with Tier III standards as it achieves NOx abatement of more than 80 %.

According to a report written by Paul Campling and Liliane Janssen (VITO), Kris Vanherle (TML), Janusz Cofala, Chris Heyes, and Robert Sander (IIASA) which describes the results of one of the sectoral studies undertaken in connection with the Service Contract on Monitoring and Assessment of Sectorial Implementation Actions (ENV.C3/SER/2011/0009) of DG Environment of the European Commission the investment and operating costs to install SCR, based on the recent study on the introduction of a NECA in the North Sea (Danish EPA, 2012), is summarized in the table below.

Table: Costs of SCR installations for marine vessels.

Cost item	Unit	New	Retrofit
Capital investment (per kW engine output)	€/kW	49.3	74.0
Interest rate	%	4%	4%
Average shipping hours	h/year	4000	4000
Lifetime of investment	years	20	15
Annuity	-	0.074	0.090
Annualized investment cost	€/MWh	0.91	1.66
Variable cost	€/MWh	5.55	5.55
Cost per MWh engine output	€/MWh	6.46	7.21
Engine efficiency		50%	50%
Cost per MWh fuel	€/MWh	3.23	3.61

V.II.II. <u>Scavange Air Moisturizing :</u>

Air from the turbocharger, after passing through the compressor, has high temperature. Seawater is injected to this high temperature air for cooling and making it saturated. Distillation process makes it possible to use sea water instead of fresh water. Humidification of air is controlled by maintaining scavenge air temperature between 60-70 Deg C. Water in saturated air reduces the peak temperature as water has higher heat carrying capacity than air.

Around 60% NOx reduction is achieved by this method. By using combination of other technologies such as EGR with Scavange Air Moisturizing, NOx Tier III standards can be achieved.

V.II.III. <u>CSNOx :</u>

Ecospec have developed a system known as CSNOx which uses fresh water or seawater to pass through Ultra Low Frequency Electrolysis system. This treated water is further mixed with to react with the exhaust gas to reduce NOx content. The system reduces CO_2, SOx and NOx in one compact equipment. This technology along with other NOx reducing methods mentioned above can be used for compliance with Tier III standards. CSNOx has an advantage of achieving high efficiency with low maintenance and power consumption.

V.II.IV. <u>Combination:</u>

Combination of Technologies having one or more combinations such as electronic engines with variable fuel timings, LNG as fuel or Direct water injection or Fuel in water emulsions etc with other NOx reducing methods can be used to comply with Tier III emission standards. These mentioned combination may or may not require exhaust gas scrubber to comply with Tier III norms.

V.III. Complying with the NOx Code

The requirements of the NOx Code are the only one of the emission regulations where the engine itself rather than the fuel or ancillary systems can be a controlling factor. Under the Code, all vessels built since 2000 must have a Technical File which identifies the engine's components, settings or operating values which influence exhaust emissions.

The file is prepared by the engine maker and approved by the flag state. It must be retained onboard for the whole life of the engine and will be used to ensure compliance. The engine to which the Technical File refers is to be installed in accordance with the rating (kW and speed) and duty cycle as approved together with any limitation imposed by the Technical File. The Technical File must, at a minimum, contain the following information:

- Identification of components, settings and operating values of the engine which influence its NOx emissions
- Identification of the full range of allowable adjustments or alternatives for the components of the engine
- A full record of the engine's performance, including its rated speed and rated power

- A system of onboard NOx verification procedures to verify compliance with the NOx emission limits during onboard verification surveys
- A copy of the test report for an engine tested for pre-certification or a test report for an engine installed onboard ship without pre-certification
- If applicable, the designation and restrictions for an engine which is a member of an engine group or engine family
- Specifications of those spare parts and components which, when used in the engine, according to those specifications, will result in continued compliance of the engine with the NOx emission limits
- The Engine International Air Pollution Prevention Certificate (EIAPP)

Compliance with the code can be achieved using one of three options alone or a combination.

The first option is to run the engine always within the parameters as laid down in the technical file and to use only OEM spare parts when any component identified in the technical file requires replacement.

The second is to install a continuous monitoring system of the type offered by manufacturers such as Kittiwake, Martek Marine, Green Instruments or Norsk Analyse, among others. Some of these systems can measure other exhaust gases and might be able to provide evidence of compliance with other regulations such as SOx emissions limits in SECAs or in ports where low-sulphur fuel is mandated.

The third option requires the engine to be tested at regular intervals by approved service providers.

Compliance.

Compliance with the provisions of Annex VI is determined by periodic inspections and surveys. Upon passing the surveys, the ship is issued an “International Air Pollution Prevention Certificate”, which is valid for up to 5 years. Under the “NOx Technical Code”, the ship operator (not the engine manufacturer) is responsible for in-use compliance.

VI. MEASUREMENT INSTRUMENTS FOR CONTINUOUS EMISSION MONITORING FROM MARITIME TRANSPORT. [15],[16],[17],[18]

The International Maritime Organization (IMO), has introduced regulations to prevent air pollution from vessels both globally and within designated sea areas, known as Emission Control Areas (ECAs). The ECAs are geographical locations and are defined as: North Baltic Seas, all North American Coasts & Caribbean coastal areas. Other areas are under evaluation by IMO.

These regulations require control on SO2, CO2 and NOX emissions. The Maritime Industry is facing challenges to either adopt new technologies such as exhaust gas cleaning systems (EGCS) or use of low sulfur residual or distillate marine fuels to comply with the ECA requirement. Engine manufacturers and ship owner are challenged to reduce NOX emissions. The new set limits in the ECAs can be achieved only with clean fuels or by making use of DeNOX abatement systems.

Ship yards, ship owners and marine ECGS manufacturers are looking to equip vessels with continuous gas analyzers for Continuous Emission Monitoring (CEM) to measure all the regulated pollutants (SO2, CO2, NOX) and to optimize fuel consumption (CO, O2) on board at the same time.

Proven analyzers and international Maritime organization (IMO) referenced technology

- Non dispersive Infrared technology for measurement of SO_2 and CO_2 as referenced by the IMO
- Proven UV technology for NO and NO_2, comparable to reference method
- Electro-chemical sensor to measure O2

Certified measurement according IMO MARPOL

- Non dispersive Infrared (NDIR) technology for SO_2 and CO_2 as mandated by the IMO
- Electro-chemical sensor technology for O_2, as mandated by IMO

Compliant to

- IMO MARPOL ANNEX 14 Res. MEPC 177 (58) (NTC)
- IMO MARPOL ANNEX 9 Res. MEPC 259 (68

VI.I. Non Dispersive IR (NDIR) technology

Non-dispersive Infrared (IR) gas analyzers utilize an IR source to direct IR radiation through a mixture of gases contained in a sample chamber. The IR energy is passed through the mixture in the sample chamber at absorption frequencies for gases whose concentration is to be determined. The detected absorption at each frequency is indicative of the concentration of the component gas having the particular absorption band

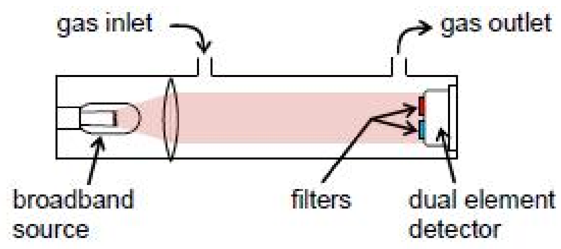
Non-dispersive infrared (NDIR) gas sensing is one of the most widely used optical gas detection techniques, and there is a wide range of cell designs in commercial manufacture. For some gases, notably carbon dioxide (CO_2), alternative (non-optical) technologies are unsuitable and therefore CO_2 detection in low-cost, volume applications often incorporates an NDIR sensor. These applications include heating, ventilation and air conditioning (HVAC) control, industrial safety especially in the brewing industry (CO_2 is an asphyxiant), process control and capnography (the measurement of time-resolved CO_2 concentration in exhaled breath) for patient monitoring for example during anaesthesia and maritime industry.

There are few alternative sensor technologies capable of detecting CO_2 at ppm concentrations. Devices have been developed based on the electrochemical principle and research is also underway on metal oxide semiconductors for CO_2. However, both techniques are known to cross-respond to other gas species, including water vapour, whereas NDIR sensors for CO_2 are considered to be specific to that species alone . Furthermore the development of metal oxide sensors capable of detecting CO_2 below 2,000ppm is "the biggest challenge" according to a recent review.

Over the last decade, the commercial market has become populated with small footprint gas sensors based on the NDIR principle. The dimensions of these sensors (a cylinder 20 mm diameter x 16.5 mm high) follow a default standard for the gas sensor industry.

These sensors are low cost, having few components (typically a simple microbulb light source, gold coated reflective light path and detector). The microbulbs used in conventional NDIR sensors have two main advantages; their spectral emission is relatively high (2 mW per steradian in a FWHM bandwidth of 0.17 µm at 4.2 µm, for one example) and the cost is low ($1-2). A key to the miniaturisation of this technology has been the integration of multiple detectors and filters into a small single package, typically a 9mm diameter TO-5 can. Commercially available sensor designs in the standard miniature format include a dual ellipsoid / reflector / ellipsoid arrangement, a pathlength arranged in the form of a spiral around the bulb / detector, and a mini integrating sphere with a rough internal surface, in which the light bounces around the internal cavity at random until it is absorbed by the sidewalls, the gas sample, or the detector.

Figure 1 shows a schematic diagram of a simple NDIR gas sensor. Typically, emission from a broadband source (such as a microbulb) is passed through two filters, one covering the whole absorption band of the target gas (in the active channel), and the other covering a neighbouring non-absorbed region (the reference channel).



VI.II. Non Dispersive UV technology

Non-Dispersive Ultra-Violet (NDUV) analysis is an absorption spectroscopy technique used for gas analysis. Ultraviolet wavelengths are used for the measurement of NO and NO2 because they are not cross sensitive to CO_2 and H_20, which do not absorb well in the UV region.

A nitrogen oxides (NOx) and sulfur dioxide (SO_2) gas analyzer using deep ultraviolet (DUV) and violet lightemitting diodes (LEDs) is developed. The LEDs with wavelengths of 280 nm and 400 nm were alternately turned on to detect SO_2 and nitrogen dioxide (NO_2) absorption. Nitric oxide (NO) was converted to NO_2 with an ozonizer. In order to reduce water interference caused by water adsorption onto an inner surface of a gas flow cell, collimating optics reducing reflected lights were designed. As a result, less than 1% by full scale (%F.S.) of fluctuation, 2%F.S. of drift and 0.5%F.S. of water interference were achieved in 0-50 ppm concentration range. Conversion efficiency from NO to NO_2 was over 95%.

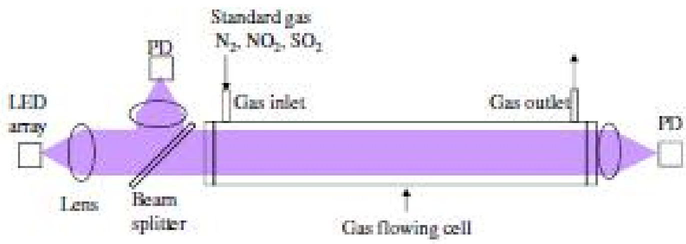


Figure 2. The experimental setup.

Fig. 2 shows the experimental setup of the NO_2 and SO_2 analyzer. The light source is an LED array in a can package. It contains two chips of LEDs of wavelength at 280 nm and a single chip of LED at 400 nm. The chips are closely aligned within 1 mm distance in order to collimate and focus lights by the same optics and control temperature of the chips by the same Peltier module. The lights from LEDs are collimated by a lens and divided into reflected lights and transmitted lights by a fused silica window. The reflected lights are focused into a silicon photodiode (Si-PD) to monitor outputs. The transmitted lights are through the gas flowing cell and focused into another Si-PD to measure gas absorptions. Collimating and focusing lights realize that the two PDs detect the lights from LEDs within the same solid angle. This is important to improve long term stability of output monitoring because angular distribution variations of light emissions from LEDs are caused by injection current and ambient temperature variations or degradation of LEDs.

The gas flowing cell is a stainless steel pipe with the length of 300 mm and the inner diameter of 24 mm. The top and bottom surfaces are sealed by CaF_2 windows to transmit UV lights. The inner surface is finished by electro-chemical-buffing, which prevents gas molecules from adsorbing the surface. The size of the inner diameter is determined so that collimated lights do not reflect the inner surface. This is effective to reduce water interference in concentration measurement. When water vapor adsorb the inner surface, UV light reflectivity changes.7 If the inner surface is used as a light guide, the reflectivity variation causes incident power change at the absorption detection PD. Thus, even though water itself has no absorption cross section at 280 nm and 400 nm, adsorbed water cause water interference.

The 280 nm LEDs and the 400nm LED are alternately turned on and off in every 12 ms to resolve NO_2 and SO_2 gas absorption. Each pulse width is 0.6 ms. Peak optical outputs are controlled around 1 mW by constant injection currents. The can package is temperature controlled by the Peltier module at 30 degrees of Celsius. Photocurrents at PDs are converted into voltages by trans-impedance amps and the voltages are integrated. Each normalized transmission is calculated by the integrated voltage at the absorption detection PD divided by that at the output monitoring PD. Using N_2, NO_2 and SO_2 standard gases, zero point and span point concentrations are calibrated in advance. NO_2 and SO_2 standard gas concentrations are 50 ppm by volume. The concentration from 0 to 50 ppm is a typical target range of continuous emissions monitoring systems applied to exhaust gas in industry. Fluctuations, drifts and water interferences in concentration measurements are evaluated in unit of percent by full scale (%F.S.).

VI.III. Commercial applications for maritime industry

Below are listed examples of commercial applications of continuous gas analyzers for maritime industry produced by ABB.

VI.III.I. ABB's photometric analyzer modules

Measurement of SOx/CO_2

The continuous gas analyzer AO2000 Uras26 is based on the Non Dispersive IR (NDIR) technology. NDIR is a referenced and recognized for monitoring SO2/CO2 ratio for IMO. The NDIR technology allows for selective measurement of SO_2 and CO_2.

ABB's Advance Optima series grant advanced capabilities and calculation of SO2 (ppm)/CO_2 (Vol. %) ratio, as specified on the MEPC 184. When burning fuels with sulfur content higher than 0.1 Vol. % in ECAs, ships must abate SO_2 and keep SO2/CO2 ratio under control at the ECGS (Exhaust Gas Cleaning System).

Measurement of NOx

The continuous gas analyzer AO2000 Limas11UV can be easily and successfully used for direct measurement of NO and NO2 at the catalytic reactor or directly at the stack. UV based technology doesn't require ozone generators, nor NO/NO_2 catalytic conversion units and allows for a direct and separate measurement of both nitrogen oxides with high repeatability and stability. The Non Dispersive UV technology has been specifically studied by ABB for NO and NO_2 analysis and offers operators a simplified approach, is easy to be used and requires no auxiliary accessories.

Direct measurement of NOx allows ships to operate engines with the highest flexibility, without any need for time consuming engine re-certifications and with no restrictions on OEM parts.

VI.III.II. GAA630-M Advanced emission monitoring system for marine applications

The GAA630-M is based on ABB's proven NDIR (non-dispersive infrared) measurement technology. The analyzer module Uras26 allows for reliable measuring and monitoring of the limit values for SO_2 and CO_2 specified by the IMO, and it can be employed for continuous monitoring of CO if required. The O_2 concentration (combustion quality index) is measured with an electrochemical sensor (ECS). The system can be equipped with an additional analyzer module to allow for NOx measurements. The Limas21 UV is a rugged photometer based on NDUV (non-dispersive ultraviolet) measurement technology specifically designed for NO and NO_2 measurements.

System config.	Sampling points	Streams	Measured components
C1	Downstream scrubber	Single	CO_2, SO_2, O_2
C2	Upstream scrubber and Downstream scrubber	Dual	CO_2 and SO_2, O_2
C3	Downstream scrubber	Dual	CO_2, SO_2, O_2
C4	Downstream scrubber	Single	CO_2, SO_2, O_2, NOx
C5	Upstream scrubber and Downstream scrubber	Dual	CO_2 and SO_2, O_2, NOx
C6	Downstream scrubber	Single	CO_2, SO_2, O_2, CO

System configuration

The system allows for simultaneous monitoring of multiple measuring points and different measured values. It can be configured for either a single stream or a dual stream sampling

System design

The GAA630-M consists of the following parts:

– Sampling probe – Sample gas line

– Sample conditioning system

– Analyzer system

The system is composed of two cabinets: One cabinet accommodates the sampling components and the other the analytical components.

The extraction of the gas from the exhaust line is done with heated sampling probes, which are installed in the line. The heated sampling line is the connection and supplying line between sampling probe and sampling cabinet. The probe and the sampling line are heated to avoid condensation.

To clean the filters in the sampling probe a back-flushing system via the filter chamber is integrated (with built-in solenoid valves). The filters are cleaned with pressurized air, every 6 hours cyclical or automatically when the flow is below the minimum value.

At the entrance of the analyzer cabinet there is a 3/2 way solenoid valve. The gas flow goes to the gas cooler and via filter, flow meter, pump and aqua stop filter to the gas analyzer.

VII. STEPS MARITIME COMPANIES SHOULD TAKE TO PREPARE FOR COMPLIANCE WITH THE EU MRV REGULATION. [12],[13],[19]

The steps of the MRV process as well as roles and responsibilities defined in the proposed MRV system are illustrated by Figure 1. As the figure shows, the Monitoring Plans as well as the CO_2 emissions and other relevant information monitored and reported will be verified by independent accredited verifiers.

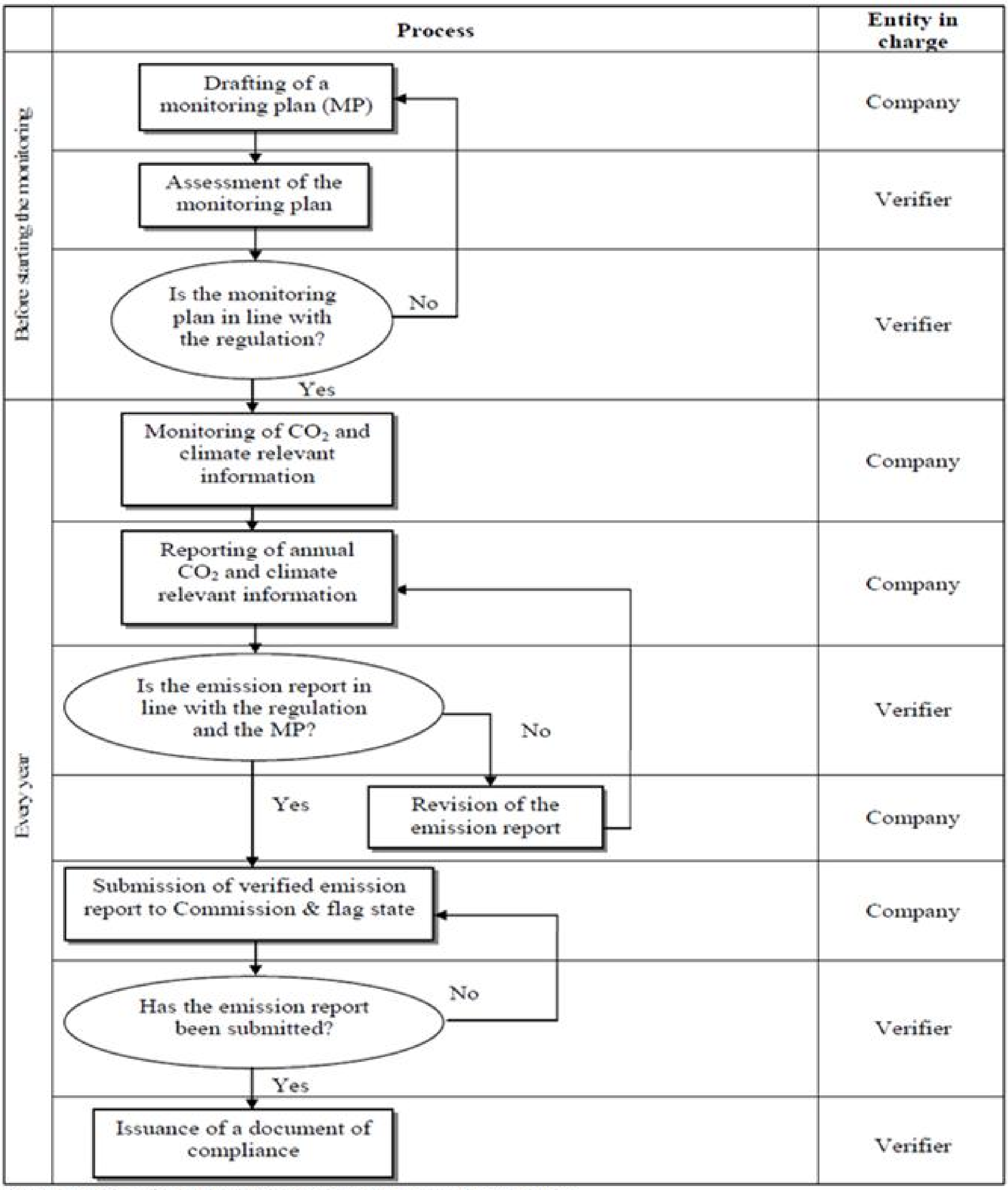


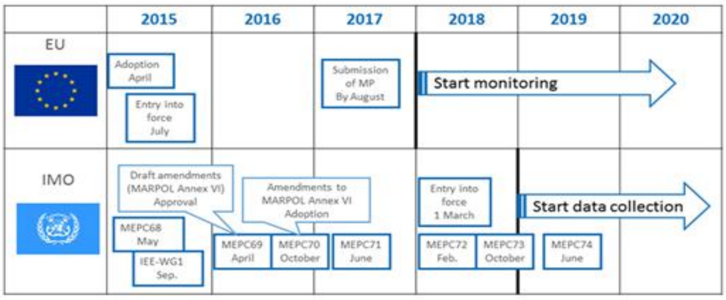
Figure 1. Steps, roles and responsibilities in the proposed MRV system.
Source: Legislative proposal to establish an EU system for monitoring, reporting and verifying (MRV) emissions from large ships using EU ports (EU). No 525/2013

The timeline for implementing the EU MRV regulation is shown summarized and visualized below.

Source: DNL GL

The IMO, adopted amendments to MARPOL Annex VI, MEPC 70 (October 2016), in order to set place a data collection system commencing in January 2019, the IMO DCS (Data Collection System for fuel oil consumption).

In the following table are summarized the timelines of the two data collection systems



As a very first step, companies should assess whether tools already in place today will suffice for the MRV regulation and its reporting needs, or whether they need to be extended or maybe even replaced by a new solution.

The main subjects that must be examined about the reporting system are the following:

- ➢ Is the system capturing all the required data?
- ➢ Is it also capable of differentiating between EU ports and non-EU ports, while reflecting on the different fuels and emissions at berth, as well as many additional details like anchoring time?
- ➢ Does it allow or repair calls in ports not subject to reporting requirements and so forth?
- ➢ Does it provide secure and accurate data transmission?
- ➢ Will I be able to efficiently extract and aggregate all the required data as necessary for the emissions report and corresponding verification?
- ➢ Is the system sufficiently implemented within the company to ensure a certain data quality which matters for MRV reporting, as data will be made publically available?

Furthermore companies should take in account that the optimal solution for the reporting system should have the flexibility to collect the data that will be required to fill in the IMO DCS (Data Collection System for fuel oil consumption) commencing in January 2019.

Below is shown summarized a condensed comparison of the two schemes

	EU MRV (MONITORING, REPORTING AND VERIFICATION)	IMO DCS (DATA COLLECTION SYSTEM)
Applicability	Ships >5,000 gross tonnage (GT) calling at any EU port will be covered	All ships ≥5,000 gross tonnage (GT) will be covered
First reporting period	January 2018	January 2019
Monitoring plan	Separate document, predefined format published by European Commission (EC)	Integrated as part of the Ship Energy Efficiency Management Plan (SEEMP, Part II). The data collection and reporting methodology shall be described in Part II and be subject to confirmation of compliance.
Reporting needs	▪ Amount and emission factor for each type of fuel consumed in total [...] ▪ CO_2 emitted: ▪ EU in-bound voyages ▪ EU out-bound voyages ▪ At berth Note: differentiation of CO_2 emissions between sea and at berth ▪ Port of departure / arrival ▪ Distance travelled ▪ Time spent at sea ▪ Cargo carried ▪ Transport work	▪ Distance travelled ▪ Amount and emissions factor for each type of fuel consumed in total [...] ▪ Hours underway ▪ DWT (as cargo proxy)
Verification	Independent accredited verifier	Flag states or recognized organizations
Reports to	Company reports to EMSA database (THETIS MRV); European Commission makes data publicly available	Flag state (or recognized organization) reports to IMO database; individual ship data is kept confidential

Source: DNL GL

Once assessed and decided, companies will need to establish management procedures to ensure the successful implementation of their monitoring systems and their proper usage by the personnel onboard their vessel and on shore.

Companies should also set up systems and mechanisms for verifying data and exported results before submitting the report.

Companies had until 31 August 2017 to create and submit a ship-specific monitoring plan to the contracted verifiers indicating the method chosen to monitor and report emissions and other relevant information for each vessel over 5,000 GT that calls at EU ports.

In general, the EU MRV regulation (2016/1927) requires the monitoring plan to be submitted per ship for verification. For companies operating several vessels, however, Art.2 of the implementing regulation (EU) 2016/1927 offers the option to split the monitoring plan into a company-specific section and a vessel-specific section, provided the respective company descriptions are applicable to all vessels of the fleet and all requirements are covered as per the template for the monitoring plan

The monitoring plan can be a time-consuming task, as the EU MRV regulation stipulates in detail the requirements for the content of the monitoring plan. These refer to ship-specific data, for example of emission sources, as well as to the development and implementation of additional management procedures.

The first reporting period commenced at the start of 2018.

Based on individual monitoring plans, vessels collect and transfer all the necessary data ashore.

At the beginning of each year companies must prepare emissions report and submit it to the contracted verifier. The emissions report documents are the results from the annual reporting and monitoring of CO2 emissions for the individual ship. Collected data sets are aggregated and enriched with further energy-efficiency-related data.

The Verification of the emissions report(s) starts in January 2019.

By 30 April of each year MRV companies shall submit to the Commission through THETIS MRV a satisfactorily verified Emissions report for each of the ships having performed EEA related maritime transport in the previous reporting period.

From 2019, by 30 June of each year MRV companies shall ensure that, all their ships having performed activities in the precedent reporting period and visiting EEA ports, carry on board a document of compliance issued by THETIS MRV. This obligation might be subject to inspections by Member States' authorities.

VIII. CONCLUSION

A robust MRV system is the foundation for implementation of any measure reducing GHG emissions of ships at EU or global level and facilitates results based monitoring of progress. Therefore, its implementation is useful, even without an MBM in place.

Lack of awareness about costs, benefits and return on investment regarding already available technologies seem to hinder the introduction of such technologies on a larger scale. This kind of information could provide useful insights into the performance of individual ships, their associated operational costs and potential resale value for the benefit of ship-owners, who would be better equipped to take decisions on major investments and to obtain the corresponding finance.

According to the results of the Impact Assessment, the implementation of MRV provides – to some extent – environmental and economic benefits of up to 2% reductions in annual GHG emissions and of up to € 1.2 billion annual net savings for the sector in 2030 due to reduced fuel bills.

The predicted fuel cost savings are expected to outweigh the costs for monitoring and reporting. An MRV system could also increase the pressure for the removal of other market barriers, such as split of incentive between ship owners and operators, by providing clarity on energy efficiency, emissions sources and abatement potential.

The EU's approach is designed to actively contribute to an agreement on global measures to reduce GHG emissions from ships in the IMO. It also allows for informed discussions in Europe on MBMs and reduction targets for the sector. Consistency will have to be ensured with the development of 2030 climate change and energy policy framework. MRV will also provide robust and comparable data to set emission reduction targets and to assess the progress of maritime transport towards a low carbon economy.

In case of successful introduction of comparable policies at IMO level, the EU MRV proposal can be integrated into a generalised MRV system

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